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GROWTH OF WHITE SPRUCE AND LODGEPOLE PINE UNDER VARIOUS TEMPERATURE AND LIGHT CONDITIONS

by

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Summary

Two Alberta seed sources of white spruce and lodgepole pine were tested for response to 9 light treatments for extending photoperiod and response to 16 combinations of day and night temperature under 2 different "daylight" and CO_2 conditions. These conditions represented a greenhouse with 16,000 lux of sodium arc lights operated throughout the night, and a more conventional greenhouse with only enough lighting to lengthen photoperiod. The results lead to the following recommendations:

1. There was no significant difference between seed sources in any of the experiments. Therefore, until there is evidence to the contrary, *grow all seed sources of the same species under the same conditions*.

2. White spruce has more exacting requirements especially for day temperature than lodgepole pine, but the optima overlap. Therefore, *both species can be grown simultaneously in the same greenhouse, if temperatures are optimized for white spruce*.

3. Both species behaved very differently when "daylight" and CO_2 timing and levels were changed. Therefore, the *temperature recommendations* listed here *apply only when all other conditions are approximately the same as the conditions used in the experiment*.

4. *Lengthening the photoperiod is vital to greenhouse success*. Incandescent light at 86 watts per m^2 on one minute every 15 throughout the night does an adequate job.

Introduction

In the spring of 1975 McBride, Regan, & Sorenson, Ltd. made a feasibility study and preliminary design of a greenhouse nursery system for Alberta Department of Energy and Natural Resources. There was the possibility that 2 or even 3 crops per year of white spruce and lodgepole pine could be grown, but it was obvious that more detailed information was needed on optimum growing regimes to avoid costly errors. As a result, Alberta Department of Energy and Natural Resources contracted with the Rocky Mountain Forest & Range Experiment Station to develop this information. The objectives of the study were to:

1. Determine the response of white spruce and lodgepole pine of Alberta seed sources to 16 combinations of day and night temperature under conditions closely matching those planned for the proposed greenhouse nursery.

   1A. Determine if there are important differences in growing requirements between seed sources within species.

   1B. Determine if the 2 species can be successfully grown together in the same greenhouse.

2. Determine the ability of 9 different night-time light treatments to maintain height growth and prevent dormancy in white spruce and lodgepole pine.

Materials and Methods

1. Temperature Study - First Run.

In order to extrapolate the results of this study to production greenhouse conditions, all conditions other than temperature were held to expected greenhouse conditions as closely as possible. However, greenhouse conditions are quite different in the winter than they are in the summer. Because of the shortage of sunlight, winter crops take longer to produce. As originally conceived, the greenhouse was to have 16,000 lux of sodium arc lights to supplement daylight during the winter. If operated at night, these arc lights would not only increase photosynthesis, but also lengthen the photoperiod. Since the winter crop would demand the most exacting greenhouse conditions, the temperature experiment was programmed to match winter growing conditions.

Spencer-Lemaire "Ferdinand" size Roottrainers[1/] were assembled with lath and wire into 6 x 6 cavity blocks and filled with 1:1 peat-vermiculite. The peat was about Von Post #4 consistancy (Robinson & Lamb 1975) from the Turtle Mountains of North Dakota, and the vermiculite had a particle size of 3-5 mm.

Three seeds per cavity of the following Alberta sources were planted, 32 blocks per source:

White spruce:	DG 79-8-6-74
	DR 46-13-5-74
Lodgepole pine:	DP 87-9-6-74
	DB 6-5-5-74

[1/] Use of trade names is for the convenience of the reader and does not imply endorsement by USDA, or that there are not other equally suitable products.

These sources were selected to represent large differences in latitude and altitude within Alberta, so that any important differences in response to photoperiod and temperature between seed sources within species would be likely to show up.

The seeded blocks were assembled on a table, soaked with water, and covered with polyethylene until germination occurred (about 10 days). The plastic was removed and the blocks moved into 4 Percival HL-60 growth chambers programmed as follows:

Timing: "Day" 7:30 AM - 5:30 PM (10 hrs)
"Night" 5:30 PM - 7:30 AM (14 hrs)

Lights: "Day": Sodium arc at 32,000 lux
"Night": " " " 18,000 lux

CO_2: Day and Night: 1200 ± 100 ppm.

Humidity: Day 70 ± 10%; Night 80 ± 10%.

Temperature: Growth Chamber No.:	1	2	3	4
Day (°C)	31	25	19	13
Night (°C)	25	19	13	7

The blocks were painted around the sides with a color code. The top color indicated day temperature and the bottom color night temperature. Twice a day the blocks were sorted between the 4 growth chambers to produce 16 combinations of day and night temperature.

After the seed coats dropped and the germination was essentially complete, the seedlings were treated with a modified Hoagland's solution at every watering. The watering schedule was determined by need (dryness), and the high temperature treatments received more than the cooler ones.

Solution was applied in excess at each watering so that some leaching occurred, which insured against salt buildup and kept the seedlings exposed to roughly constant nutrient conditions.

After the danger of damping off was largely past (age three weeks) the seedlings were thinned to 1 per pot.

The seedlings were grown until the average tree in the best treatment was about 100 mm tall and an estimated 0.5 gm dry weight. The seedlings were photographed, bare rooted, and the following measurements taken on the 25 interior seedlings in each 6 x 6 block:

Height (mm ± 1) root collar to bud or apical meristem

Caliper (mm ± 0.1) at root collar

Fresh weight (mg ± 1) of roots and shoots

Dry weight (mg ± 1) " " " "

For each measurement on each seed source a two-way analysis of variance was performed:

Source	Degrees of Freedom
Day temperature	3
Night temperature	3
Day/night interaction	9
Blocks	1
Error	783
Total	799

The error mean square was used to calculate the coefficient of variability.

Mean values for each temperature treatment were calculated for each seed source and measurement. These were expressed as a percent of the largest value and plotted on graph paper with day temperature as the abscissa and night temperature the ordinate. The 90, 80, 70, etc. percent isolines were drawn by hand by linear interpolation in 2 dimensions. Judgement as to how best to smooth the curves was guided by the following principles:

1. Maximum leeway is 1/4 of the coefficient of variability.
2. Isolines tend to be parallel.
3. Isolines do not have sharp corners.

2. Temperature Study - Second Run.

While the first temperature study was in progress, Alberta Energy decided not to install arc lights in the proposed greenhouse. Plans to grow crops in the winter were dropped. Instead, one crop a year would be grown in a less expensive, more conventional facility. Since the information developed in the first run might not apply under the new conditions, it was necessary to make a second run in which conditions would more nearly match a summer growing schedule in a conventional greenhouse. The growth chambers were programmed as follows:

Timing: "Day": 4:30 PM - 8:30 AM (16 hrs)
"Night": 8:30 AM - 4:30 PM (8 hrs)

Lights: "Day": Sodium arc at 32,000 lux
"Night": No light except 1 minute every 15 of incandescent light at 430 lux throughout the "night" to make a 24 hour photoperiod.

CO_2: Day: 1200 ± 100 ppm.
Night: 350 ± 25 ppm.

Humidity: Day 70 ± 10%

Night 80 ± 10%

Temperature:

Growth Chamber No.	1	2	3	4
Day (°C)	34	28	22	16
Night (°C)	28	22	16	10

Since the Ferdinand Roottrainers did not withstand diurnal handling well, BC/CFS Styroblock 2's were cut into units of 20 cavities, color coded as before, and used for the second run.

Growing medium was 1:1 peat-vermiculite. Vermiculite was the same as before, but the peat was a Canadian sphagnum coarser than before with a Von Post consistancy of about 2.

Replication was reduced to a single block per seed source per temperature treatment, and 3 more seed sources obtained from the State of Alaska were added:

White spruce	L-274	(Fairbanks)
White spruce	L-224	(Kenai)
Lodgepole pine	L-236	(Whitehorse, Y.T.)

All other operations and analyses were the same as the first run.

3. Photoperiod Study

Nine 200 cavity blocks of Weyerhauser "pine" cells were filled with the same peat-vermiculite mix used in the first temperature study, and 50 cells of each block seeded with the same seed sources of white spruce and lodgepole pine. The blocks were placed in a standard glass greenhouse with the following conditions:

Timing: Seed planted Dec. 3, 1975.

Trees harvested in July, 1976.

Approximate Temperature & Humidity:

	Day (°C)		Night (°C)		R.H. (%)
Month	Max	Mean	Mean	Min	
Dec	20	19	18	16	25-50
Jan	20	19	17	16	25-50
Feb	25	20	17	15	40-60
Mar	25	20	20	16	40-60
Apr	26	23	20	17	30-50
May	30	24	20	17	30-80
Jun	32	25	20	17	40-90

CO_2: Ambient (325 ± 25 ppm) except in January and February when CO_2 level was elevated to 1000 ± 200 ppm.

Photoperiod:

The 9 blocks were placed on a greenhouse bench equipped with a device which closed automatically in the evening and opened in the morning to divide the bench into 9 light-tight compartments. One block was placed in each compartment. Each compartment was given a different light treatment by means of a single bulb 80 cm above the containers. Treatments were:

Treatment No.	Bulb Type	Size (watts)	Intensity (lux)	Duration
1	none	0	0	none
2	tungsten incandescent	1	43	1 minute every 15 throughout the night (24 hr day-intermittent)
4	"	15	160	"
5	"	40	270	"
6	"	100	1200	"
7	cool white fluorescent	22	950	"
8	tungsten incandescent	100	1200	continuous all night (24 hr day)
9	"	"	"	continuous during night except for 3 hrs (21 hr day)

Each compartment was attached to an air exhaust blower to minimize temperature differences between compartments at night. Each month the positions of the various treatments on the bench were re-randomized to reduce the position effect caused by non-uniformity of daylight and temperature conditions in the greenhouse. The compartment opening and closing was synchronized with the natural day, so that it was closed and the photoperiod treatments operating whenever it was dark up to a day length of 16 hrs. In June this meant shortening the natural day somewhat.

After the seed coats were shed the seedlings were watered as needed with a modified Hoagland's solution. The seedlings were grown until the average tree in the best treatment was as large as desired. They were then photographed, and height, caliper, and fresh and dry weight, were measured as in the temperature study.

Results and Discussion

1. Temperature Study

Figures 1-28 show the growth response in height, caliper, and dry weight, of white spruce and lodgepole pine of the two Alberta seed sources for two different light and CO_2 regimes.

List of Figures

Growth of seedlings as a function of day and night temperature.

Figure	Species	Source	Growth Parameter	Growth Chamber Run
1	Lodgepole pine	DB-6-55-74	Height	1
2	"	"	Caliper	1
3	"	"	Dry weight	1
4	"	DP 87-9-6-74	Height	1
5	"	"	Caliper	1
6	"	"	Dry weight	1
7	White spruce	DR 46-13-5-74	Height	1
8	"	"	Caliper	1
9	"	"	Dry weight	1
10	"	DG 79-8-6-74	Height	1
11	"	"	Caliper	1
12	"	"	Dry weight	1
13	Lodgepole pine	DB-6-55-74	Height	2
14	"	"	Caliper	2
15	"	"	Dry weight	2
16	"	"	Dry weight R/S	2
17	"	DP 87-9-6-74	Height	2
18	"	"	Caliper	2
19	"	"	Dry weight	2
20	"	"	Dry weight R/S	2
21	White spruce	DR 46-13-5-74	Height	2
22	"	"	Caliper	2
23	"	"	Dry weight	2
24	"	"	Dry weight R/S	2
25	"	DG 79-8-6-74	Height	2
26	"	"	Caliper	2
27	"	"	Dry weight	2
28	"	"	Dry weight R/S	2

For each of the 4 seed sources the analysis of variance showed that day temperature, night temperature, and their interaction were all significant (a trivial finding, actually). The coefficients of variability for height and caliper were about 3-5% and dry weight 6-10%, which is quite low. Since differences approximately double the coefficient of variability are significant at the 5% probability level, a significant difference on the height and caliper graphs would be about 3/4 the distance between contour lines, and for dry weight about 1 1/2 times contour line distance. This is only approximate, however, because the graphs are hand drawn. Nevertheless, it is a useful indication of how much confidence can be placed in the temperature information.

One important conclusion is that there are no significant differences between seed sources within species. This includes the 3 Alaska seed sources as well. In both growth chamber runs the optimum growing temperatures for different seed sources were the same within the limits of error. This is the same as we have found for the other species we have tested. It is fortunate, because it means that the same greenhouse growing conditions can probably be used successfully for any seed source of white spruce or lodgepole pine.

There are distinct differences in the growing temperature optima between white spruce and lodgepole pine. White spruce has a relatively narrow day temperature optimum around 22°, while lodgepole pine grows well under a wider range of conditions. The optimum ranges overlap well enough so that the two species can be grown together in the same greenhouse, if conditions are optimized for white spruce. Table 1 shows recommended day and night thermostat setpoints and a permissible range which will keep most growth parameters within 90% of maximum. Table 1 is for a conventional greenhouse with high CO_2 during summer daylight hours and intermittent low intensity light at night to lengthen photoperiod to 24 hours. The choice of setpoint and range is based first on maintaining maximum growth rate, and second on economic considerations. In most cases night temperatures must be maintained by heating, therefore, the setpoint is selected near the lower end of the optimum. Ability to maintain day temperature will vary with the season and cloudyness. When heating requirements make the recommended setpoint too expensive to maintain, or summer high temperatures exceed the cooling capacity, the setpoint can be adjusted with minimum loss of growth by consulting figures 1-28.

Dry weight root/shoot ratio was calculated, converted to percent of maximum, and graphed in the same manner as the other growth parameters. Root/shoot was used instead of shoot/root so that all parameter graphs could be directly compared, that is, the higher the value, the better. Both seed sources of lodgepole pine were essentially the same in that R/S was highest at the coldest day and night temperature, but the R/S of DP-8796 declined faster as either day or night temperature increased. Maximum R/S of lodgepole pine did not overlap well with recommended growing temperatures based on height, caliper, and dry weight. This has been observed with other species and is not necessarily bad. First, this experiment was terminated at what would have been the end of the exponential growth phase in the greenhouse, but before hardening began. During the first stage of hardening of container stock root growth continues, but top growth slows. This usually increases the root/shoot ratio. Second, data on the effect of root/shoot ratio on outplanting success of container stock is meagre. There is no point in slowing growth in order to increase R/S unless it is really needed.

The two white spruce seed sources had very different R/S patterns, but maximum values overlapped better than in the case of lodgepole pine.

Table 2 assumes continuously high CO_2 and continuous sodium arc light at 18,000 lux at night and 32,000 lux during a 10 hour day. This will not be applicable to the greenhouse system as currently envisioned.

There are large differences in response to temperature between the two growth chamber runs. In the first there was no dark period at all. Two levels of light intensity were used, but both were high enough for photosynthesis. The CO_2 level remained continuously high. The foliage of both species in all of the treatments was somewhat chlorotic, probably due to solarization (Ronco 1970). In previous experiments similar symptoms have appeared, but were generally confined to the fastest growing treatments. I believe that mineral nutrient imbalance was responsible for that, since all treatments, regardless of growth rate, were receiving the same nutrient solution.

Mineral nutrient requirements under optimum temperature, humidity, and high CO_2 atmospheres have not been studied, and the currently recommended formulations may be inadequate.

The foliage of both species in the second run appeared dark green, and the trees took less time to reach full size than in the first run. The color difference between the first and second runs reinforces my belief that the cause of chlorosis was excessive light. The second run had a dark period interrupted by just enough light to prevent dormancy. The difference in rate of growth may be partly due to a more favorable light regime and more healthy foliage, but is certainly due at least in part to wider spacing ($\underline{1033/m^2}$ vs $\underline{1580/m^2}$) of the Styro 2 cavities compared to the Ferdinand container (Tinus 1975). On the other hand the Styro 2 is slightly smaller (35 ml vs 38 ml) than the Ferdinand.

Under continuous high intensity light the "night" temperature optimum is much higher than under "dark night" conditions, in fact many of the permissible ranges, comparing the first and second runs, do not even overlap. Neither are "lighted night" optima necessarily the same as "day" temperature optima. This shows how vitally important it is that all growing conditions are controlled when one variable such as temperature is manipulated. We have followed this practice carefully in previous temperature studies of different species. There are now numerous cases where greenhouse crops have been successfully grown using the recommendations resulting from these growth chamber temperature studies. In several cases the first operational crop was better than anything we have grown in our greenhouses at Bottineau. Thus, we knew we could extrapolate to greenhouse conditions when the growth chambers were programmed to match greenhouse conditions as closely as possible. However, this study is the first in which we had a direct comparison between two different light and CO_2 conditions, using the same species and seed sources.

Conventional logic leads one to expect higher temperature optima under higher light intensity and high CO_2 (Tinus 1974). High CO_2 suppresses photorespiration and increases the diffusion gradient from the outside air to the chloroplast. Under high light intensity the dark reactions of photosynthesis are rate limiting and higher temperature speeds them up. Suppression of photorespiration prevents the photosynthate from being consumed so rapidly, especially at high temperature.

It is surprising that "dark night" temperature optima should be so high. Current dogma says that cool nights lower respiration and conserve photosynthate (Meyer & Anderson 1952, Kramer & Kozlowski 1960). However, translocation and assimilation must also be slowed, and under high CO_2 and adequate light intensity during the day, photosynthate supply could accumulate in the leaf and reduce the photosynthetic rate, if it is not removed fast enough.

2. Photoperiod Study

Figures 29 and 30 show the relation between light treatment used to extend the photoperiod and height growth of the 2 Alberta seed sources of white spruce and lodgepole pine. With no added light at night the white spruce set bud in the cotyledon stage, and much of it died before the end of the study. The lodgepole pine grew some beyond the cotyledon stage but quickly set bud, also. With adequate light both species continued growth, the spruce becoming 5 times taller and the pine 2.5 times taller than with no light added. There was no significant difference in behavior between seed sources within species. Both species responded well to intermittent incandescent light. The lower threshold was between 43 and 75 lux and response to 270 lux intermittent light was not significantly less than 1200 lux either intermittent or continuous. Fluorescent light was not as effective as incandescent light, and a 21 hr day of continuous incandescent light was either less effective or not significantly different from continuous light at 1200 lux or intermittent light at 270 or 1200 lux.

Many other species we have tested have behaved the same way. Incandescent light at 270 lux 1 minute out of 15 throughout the night is an efficient way to prevent dormancy. It represents installed lighting equivalent to 86 watts per m^2. Less light will result in less growth. More light will not increase growth significantly, but it would provide an additional margin for error, and certainly would not hurt anything. These lights may be operated in separate banks in sequence so that the electrical wiring and entrance required is only 1/15 the installed capacity of the whole system. A greenhouse so equipped will successfully grow not just white spruce and lodgepole pine, but most of the species we have tested.

The results show that photoperiod control is vital to the success of greenhouse culture of Alberta sources of white spruce and lodgepole pine.

Table 1.--Recommended day and night temperatures (°C) and permissible ranges to maintain growth rate at 90% of maximum or better. Assumes conventional greenhouse with high CO_2 during summer daylight hours and intermittent low intensity light at night to lengthen photoperiod.

		Day		Night	
Species	Source	Setpoint	Range	Setpoint	Range
Pinus contorta	DP-8796	25	22-28	16	14-19
" "	DB-655	25	22-28	16	14-19
" " (Whitehorse, Y.T.)	L-236	22	20-24	19	16-20
Picea glauca	DG-7986	22	21-25	19	16-20
" "	DR-46135	22	20-25	16	13-20
" " (Kenai, Alas.)	L-224	22	20-25	19	16-26
" " (Fairbanks, Alas.)	L-274	22	20-24	16	13-22

Table 2.--Recommended day and night temperatures (°C) and permissible ranges to maintain growth at 90% of maximum or better. Assumes continuously high CO_2 and continuous sodium arc light at 18,000 lux at night, and 32,000 lux during a 10 hour day.

Species	Source	Day		Night	
		Setpoint	Range	Setpoint	Range
Pinus contorta	DP-8796	31	19-33	22	18-26
" "	DB-655	25	23-27	25	24-26 +
Picea glauca	DG-7986	19	16-25	23	22-26
" "	DR-46135	19	17-22	24	22-26

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Figure 1.--Growth in percent of maximum as a function of day and night temperature (°C).

Pinus contorta Height (DB-655 Run I)

Max. Ht. = 68 mm

Std. Error = 2.7%

	Day	Night
Optimum (90%)	12-32 or 29-32	24-26 or 12-17
Acceptable (70%)	12-19 or 19-32	18-26 or 11-26

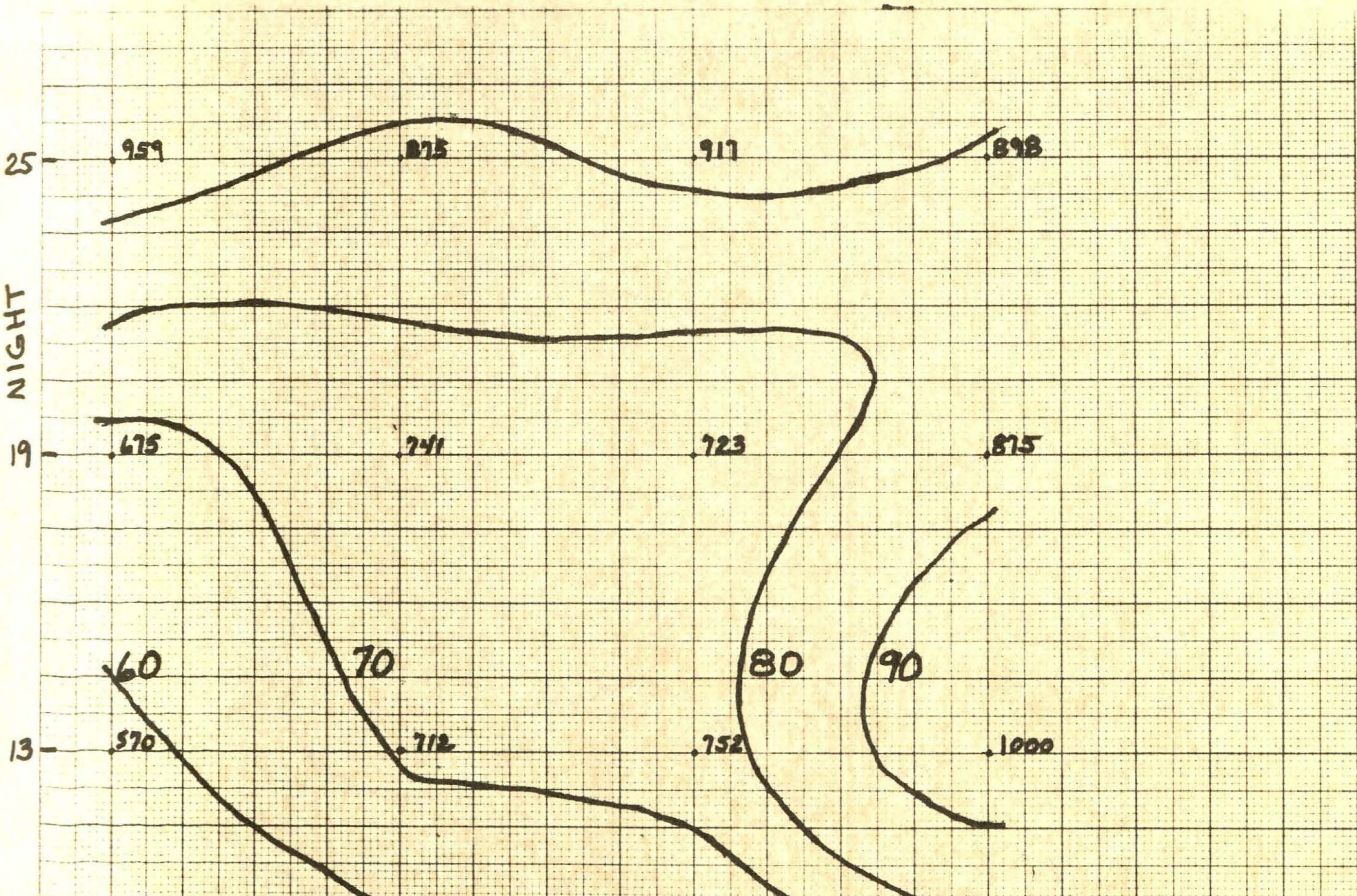


Figure 2.--Growth in percent of maximum as a function of day and night temperature (°C).

Pinus contorta Caliper (DB-655 Run I)

Max. Caliper = 1.91 mm

Std. Error = 2.6%

	Day	Night
Optimum (90%)	12-26 or 26-32	23-26 or 13-26
Acceptable (70%)	12 - 32	10 - 26

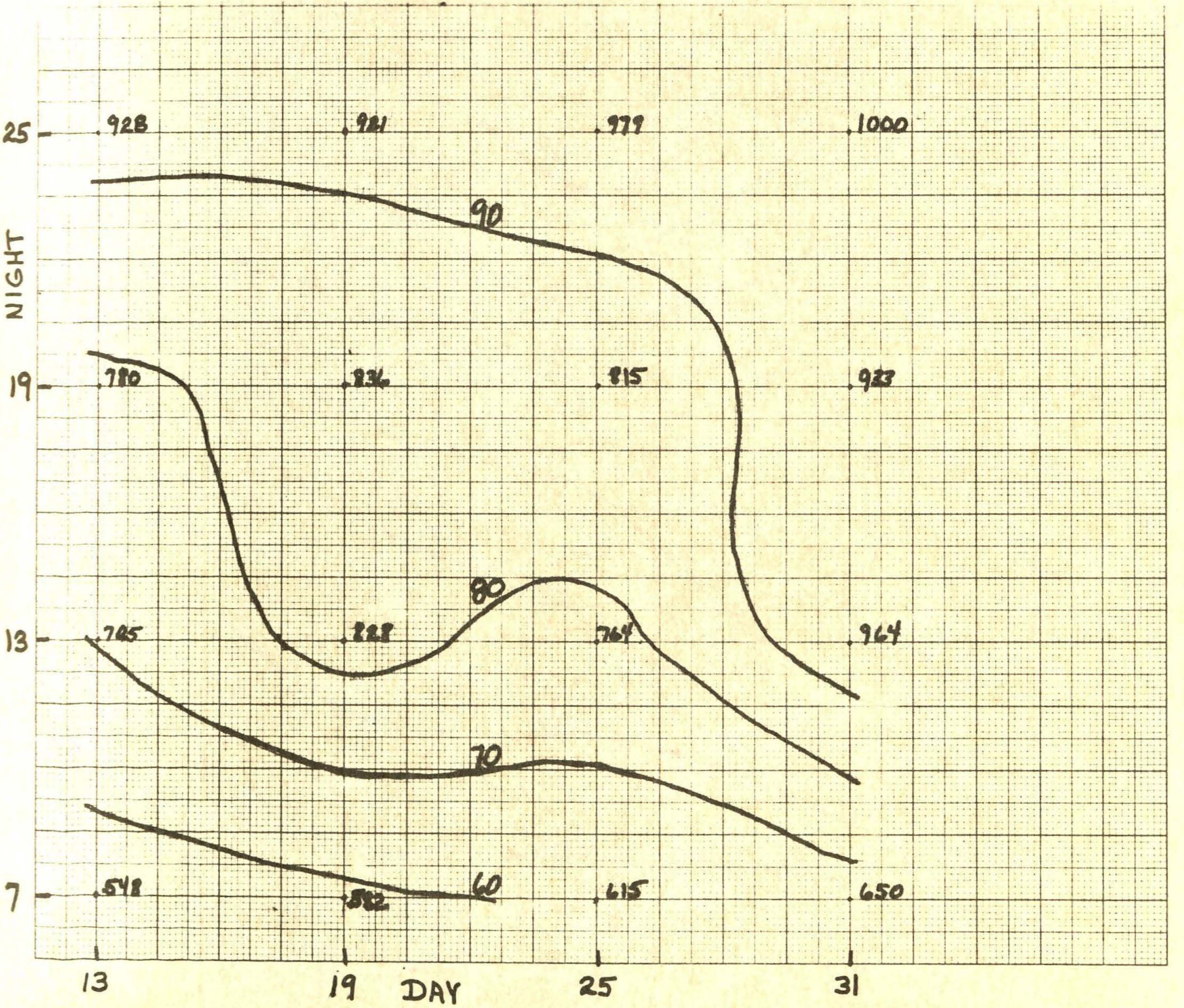


Figure 3.--Growth in percent of maximum as a function of day and night temperature (°C).

Pinus contorta Dry Weight (DB-655 Run I)

Max. Dry Wt. = 0.59 gm

Std. Error = 9.1%

	Day	Night
Optimum (90%)	23 - 27	24 - 26
Acceptable (70%)	15 - 32	22 - 26

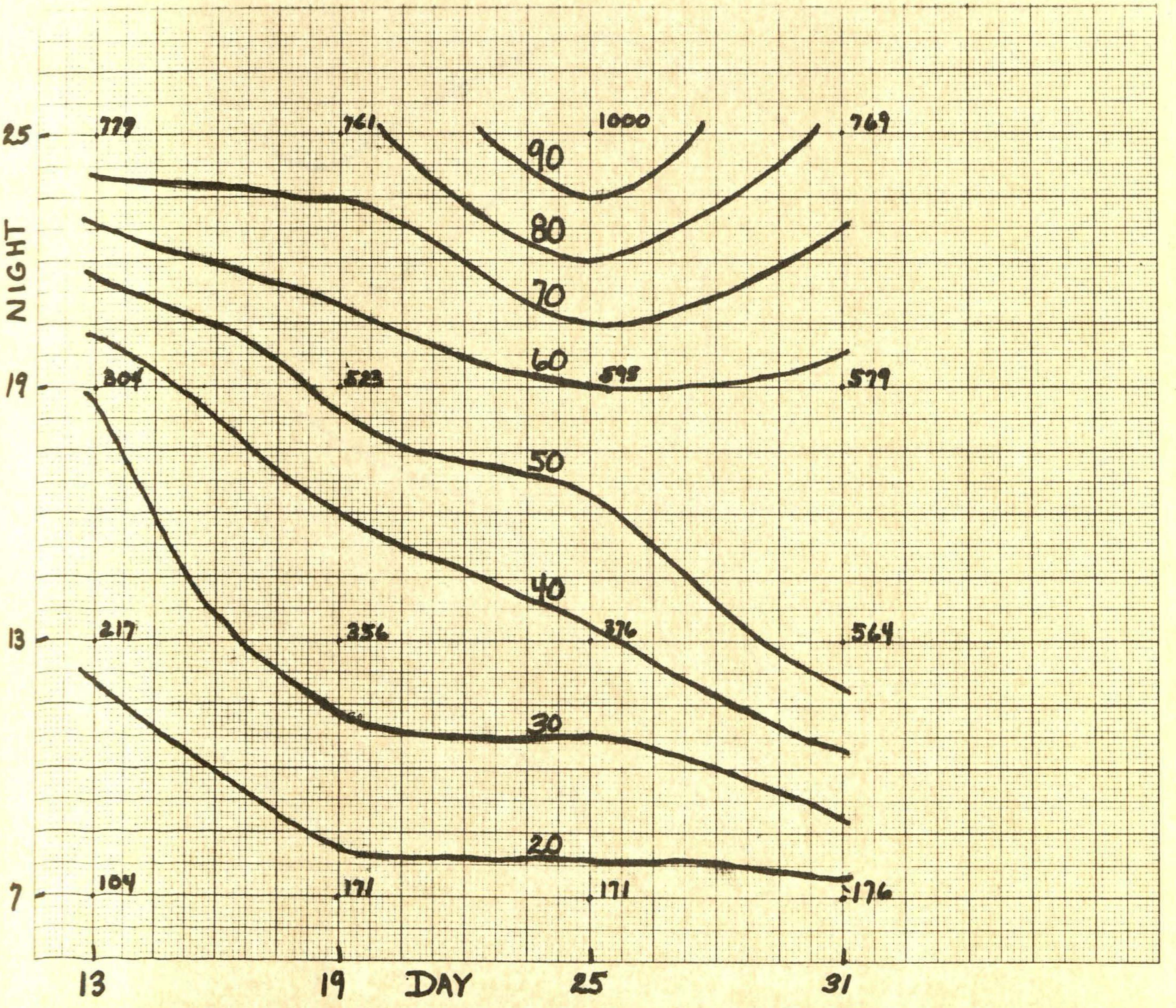


Figure 4.--Growth in percent of maximum as a function of day and night temperature (°C).

Pinus contorta Height (DP-8796 Run I)

Max. Ht. = 78 mm

Std. Error = 2.9%

	Day	Night
Optimum (90%)	30-32 or 18-20	11-26 or 24-26
Acceptable (70%)	13-22 or 22-32	19-26 or 10-26

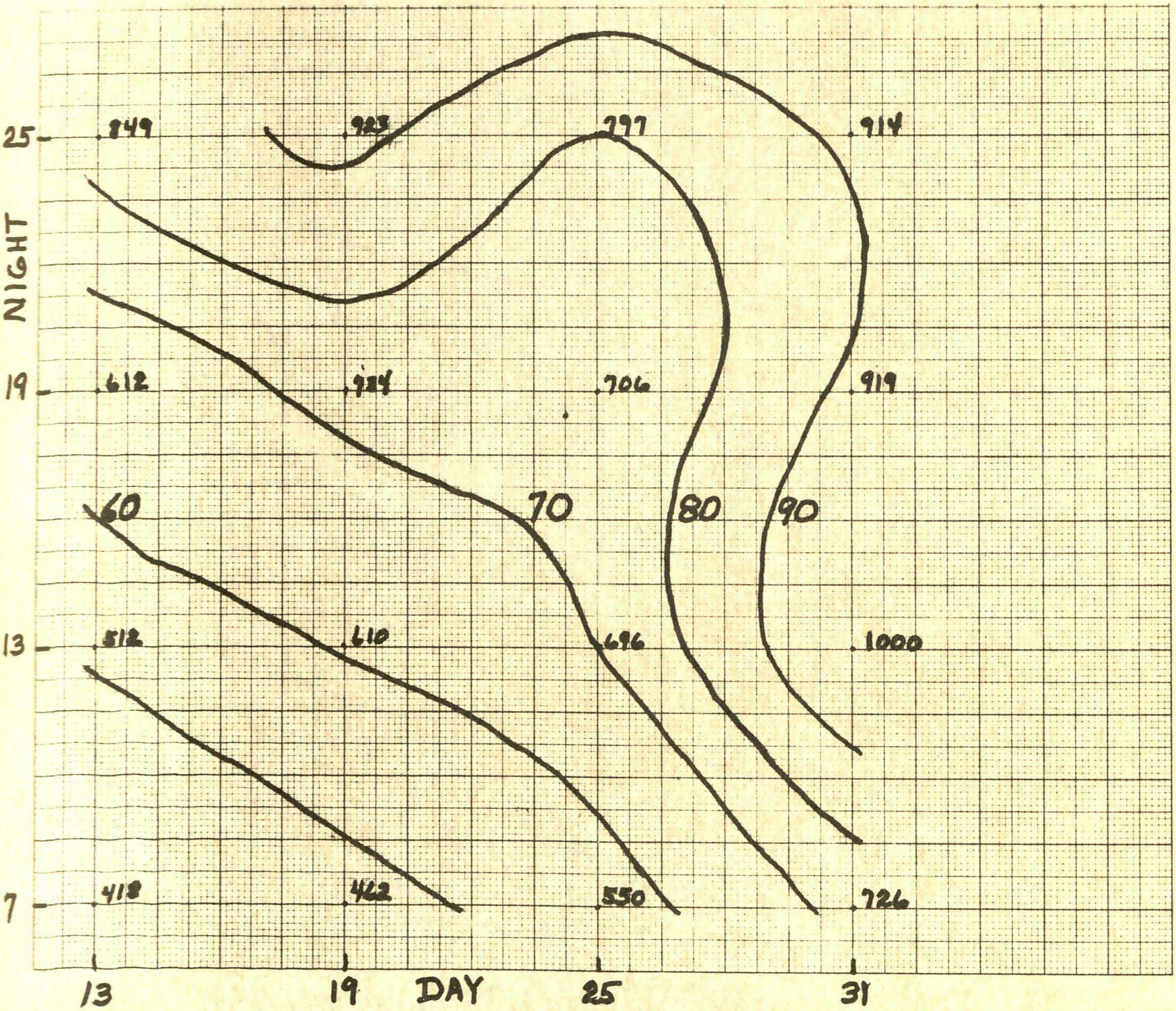


Figure 5.--Growth in percent of maximum as a function of day and night temperature (°C).

Pinus contorta Caliper (DP-8796 Run I)

Max. Caliper = 1.93 mm

Std. Error = 2.9%

	Day	Night
Optimum (90%)	18-26 or 26-32	21-26 or 17-26
Acceptable (70%)	13-16 or 16-32	16-26 or 11-26

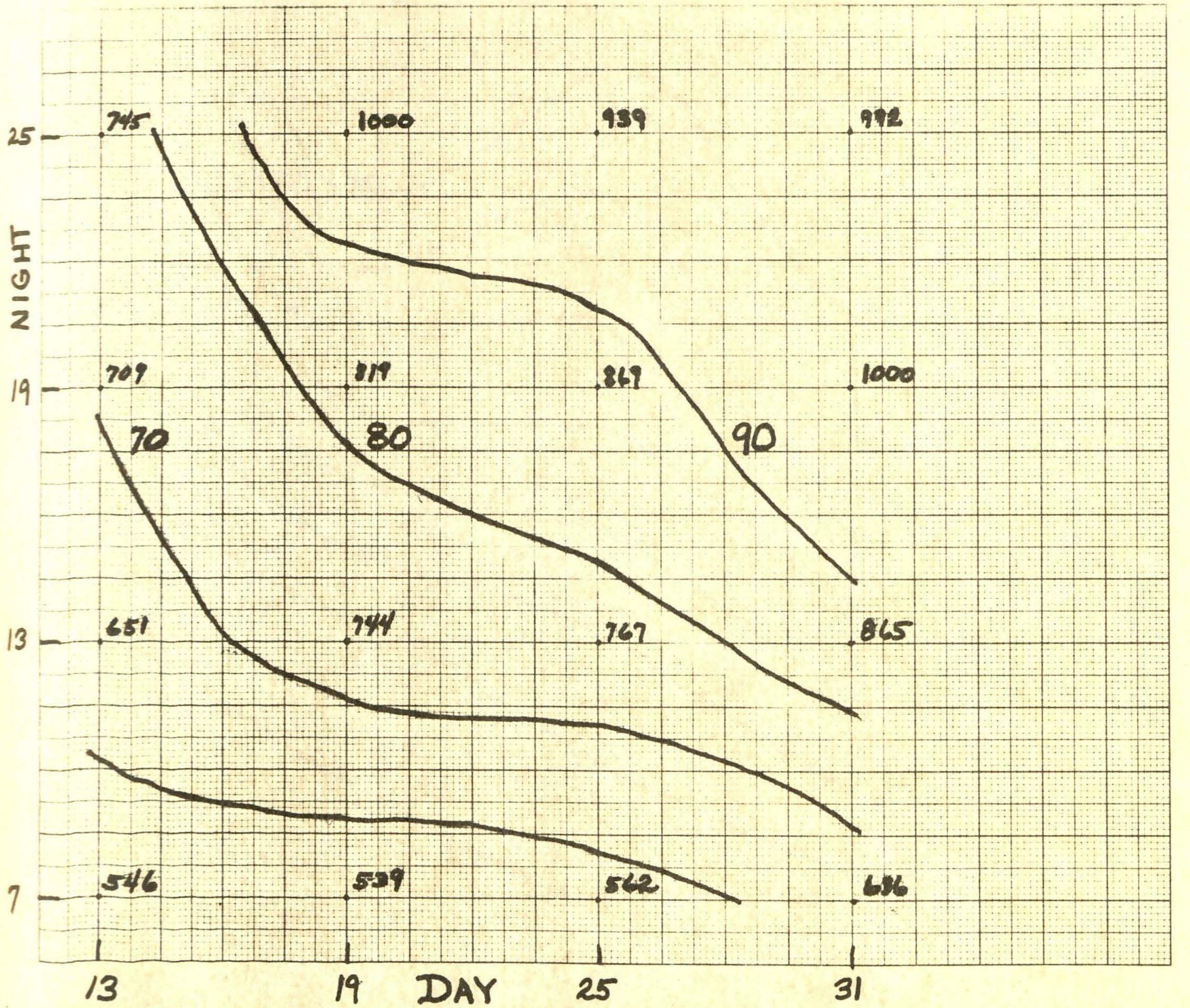


Figure 6.--Growth in percent of maximum as a function of day and night temperature (°C).

Pinus contorta Dry Weight (DP-8796 Run I)

Max. Dry Wt. = 0.59 gm

Std. Error = 8.8%

	Day	Night
Optimum (90%)	18 - 32	24 - 26
Acceptable (70%)	17 - 32	20 - 26

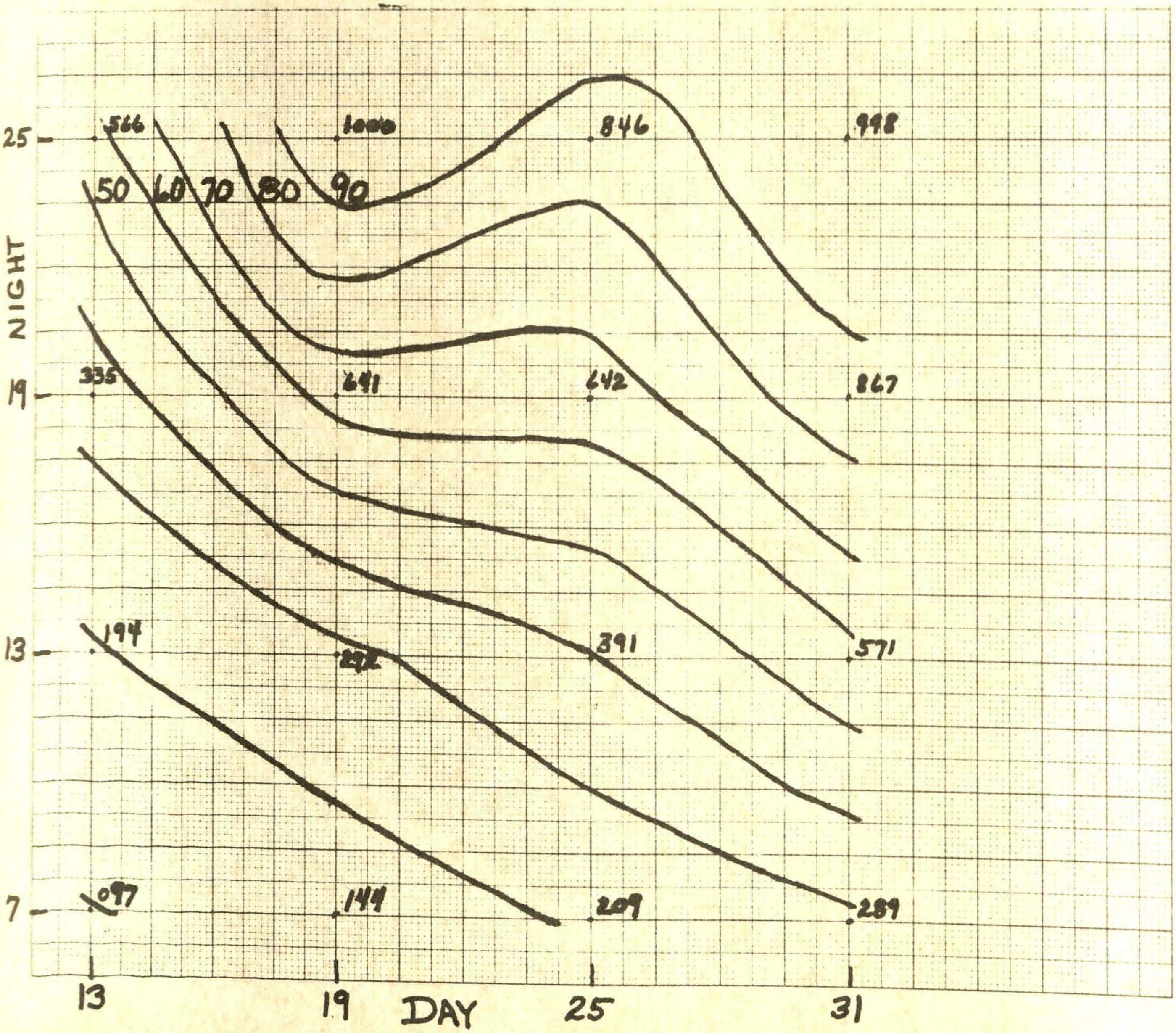


Figure 7.--Growth in percent of maximum as a function of day and night temperature (°C).

Picea glauca Height (DR-46135 Run I)

Max. Ht. = 88 mm

Std. Error = 2.8%

	Day	Night
Optimum (90%)	14 - 24	23 - 26
Acceptable (70%)	13 - 32	17 - 26

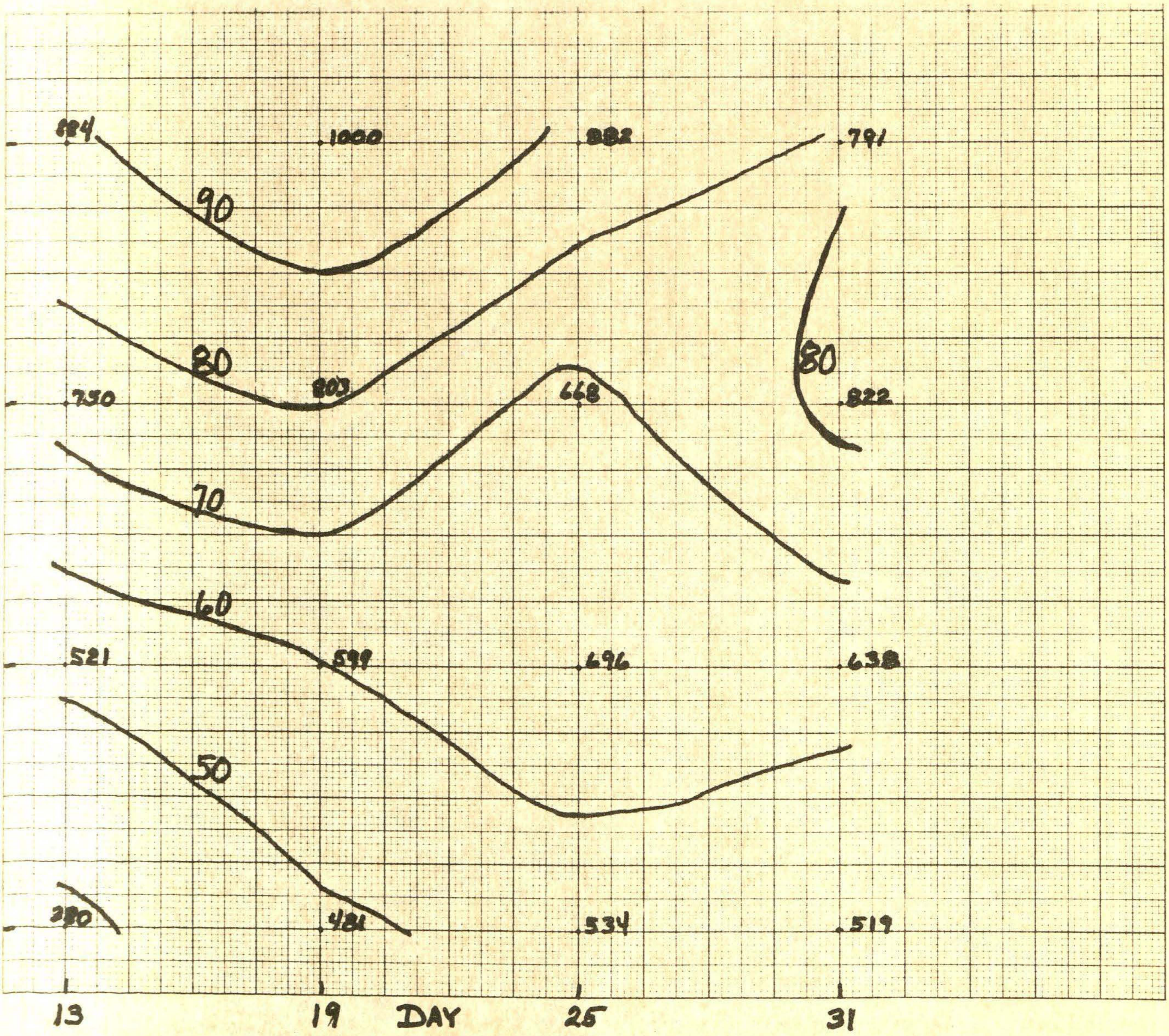


Figure 8.--Growth in percent of maximum as a function of day and night temperature (°C).

Picea glauca Caliper (DR-46135 Run I)

Max. Caliper = 1.77 mm

Std. Error = 3.0%

	Day	Night
Optimum (90%)	16 - 32	19 - 26
Acceptable (70%)	12 - 32	10 - 26

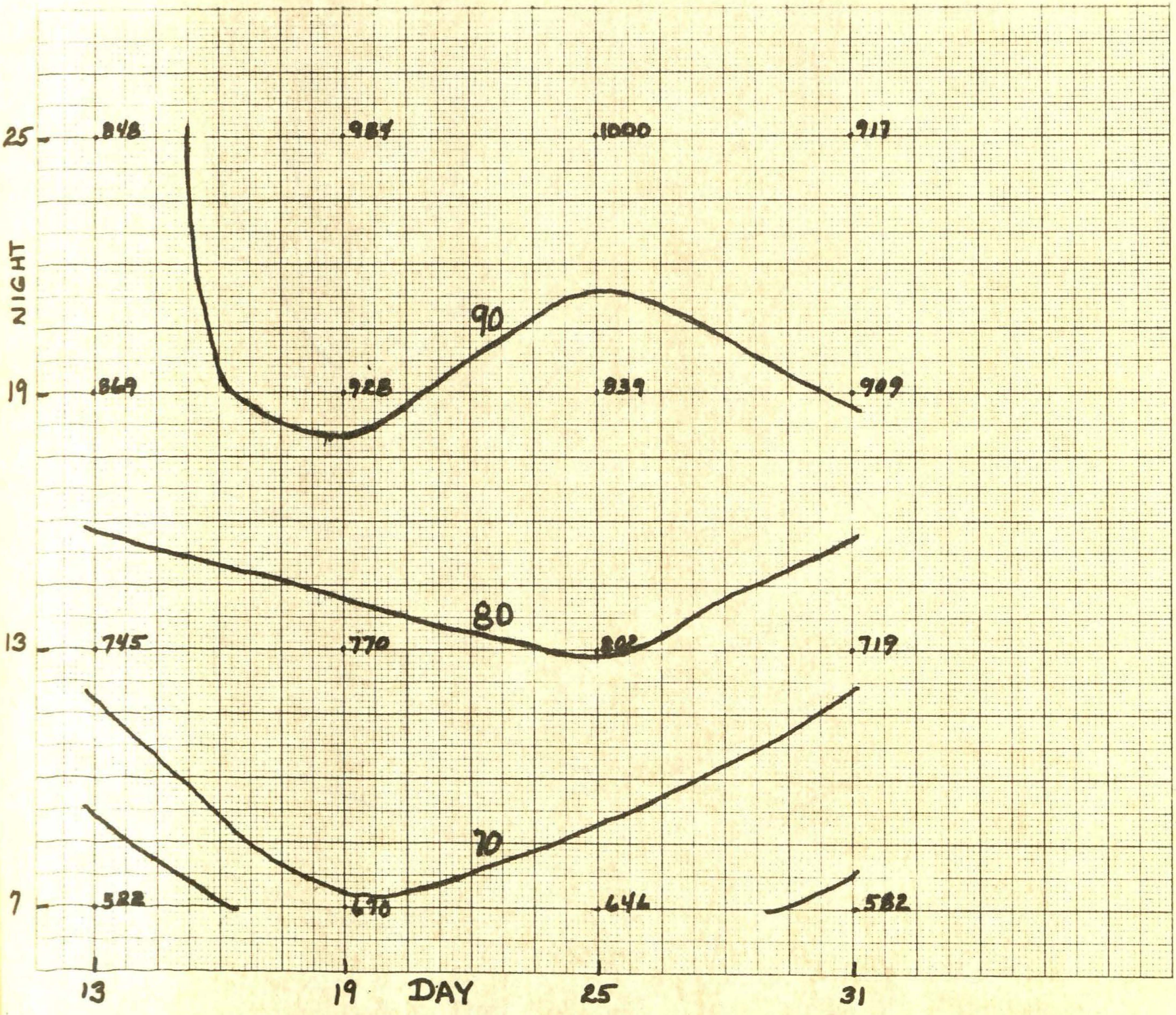


Figure 9.--Growth in percent of maximum as a function of day and night temperature (°C).

Picea glauca Dry Weight (DR-46135 Run I)

Max. Dry Wt. = 0.37 gm

Std. Error = 8.4%

	Day	Night
Optimum (90%)	18 - 21	23 - 26
Acceptable (70%)	15 - 24	19 - 26

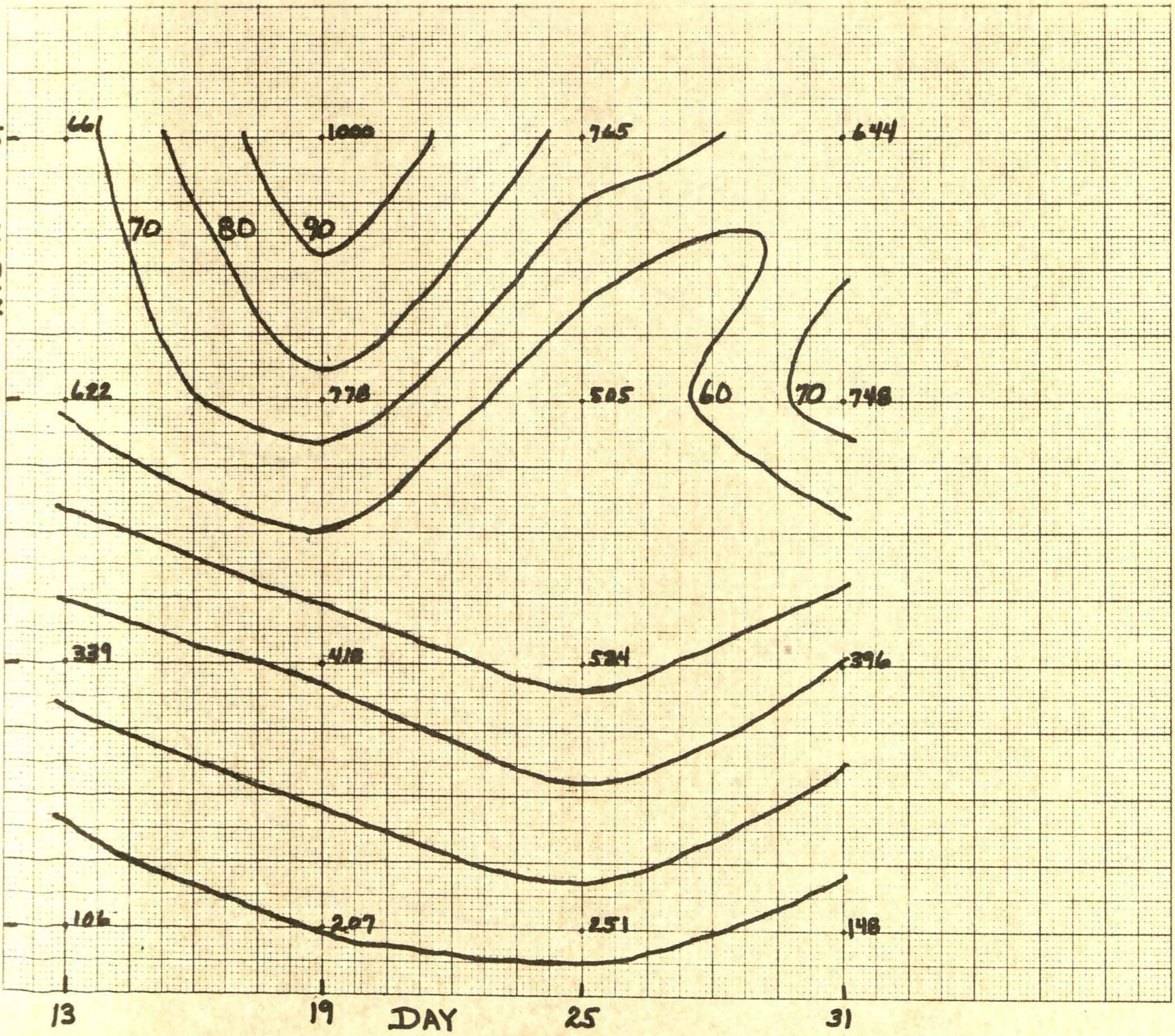


Figure 10.--Growth in percent of maximum as a function of day and night temperature (°C).

Picea glauca Height (DG-7986 Run I)

Max. Ht. = 89 mm

Std. Error = 3.0%

	Day	Night
Optimum (90%)	12 - 22	22 - 26
Acceptable (70%)	12 - 32	13 - 26

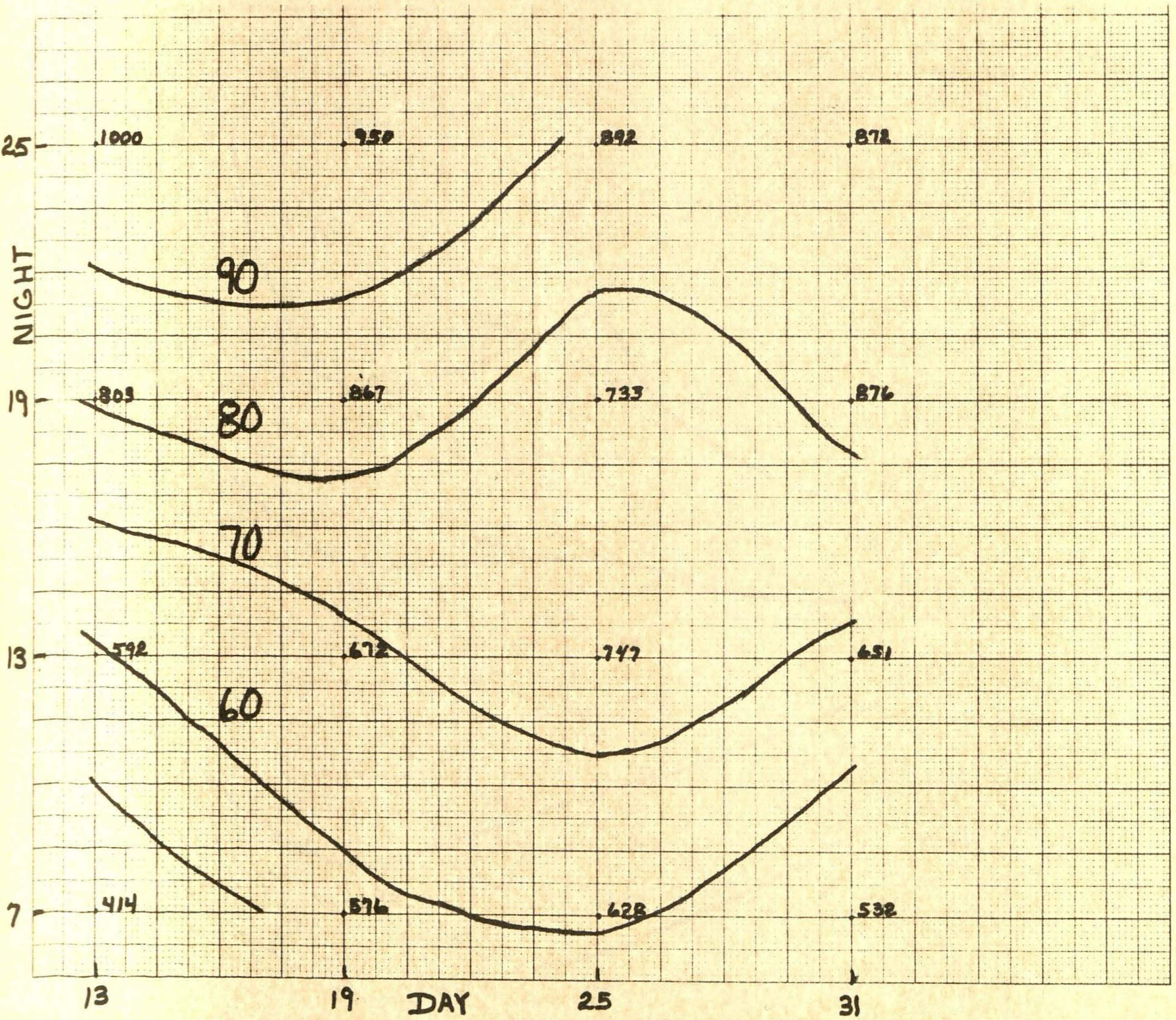


Figure 11.--Growth in percent of maximum as a function of day and night temperature (°C).

Picea glauca Caliper (DG-7986 Run I)

Max. Caliper = 1.79 mm

Std. Error = 2.7%

	Day	Night
Optimum (90%)	17 - 32	18 - 26
Acceptable (70%)	12 - 32	12 - 26

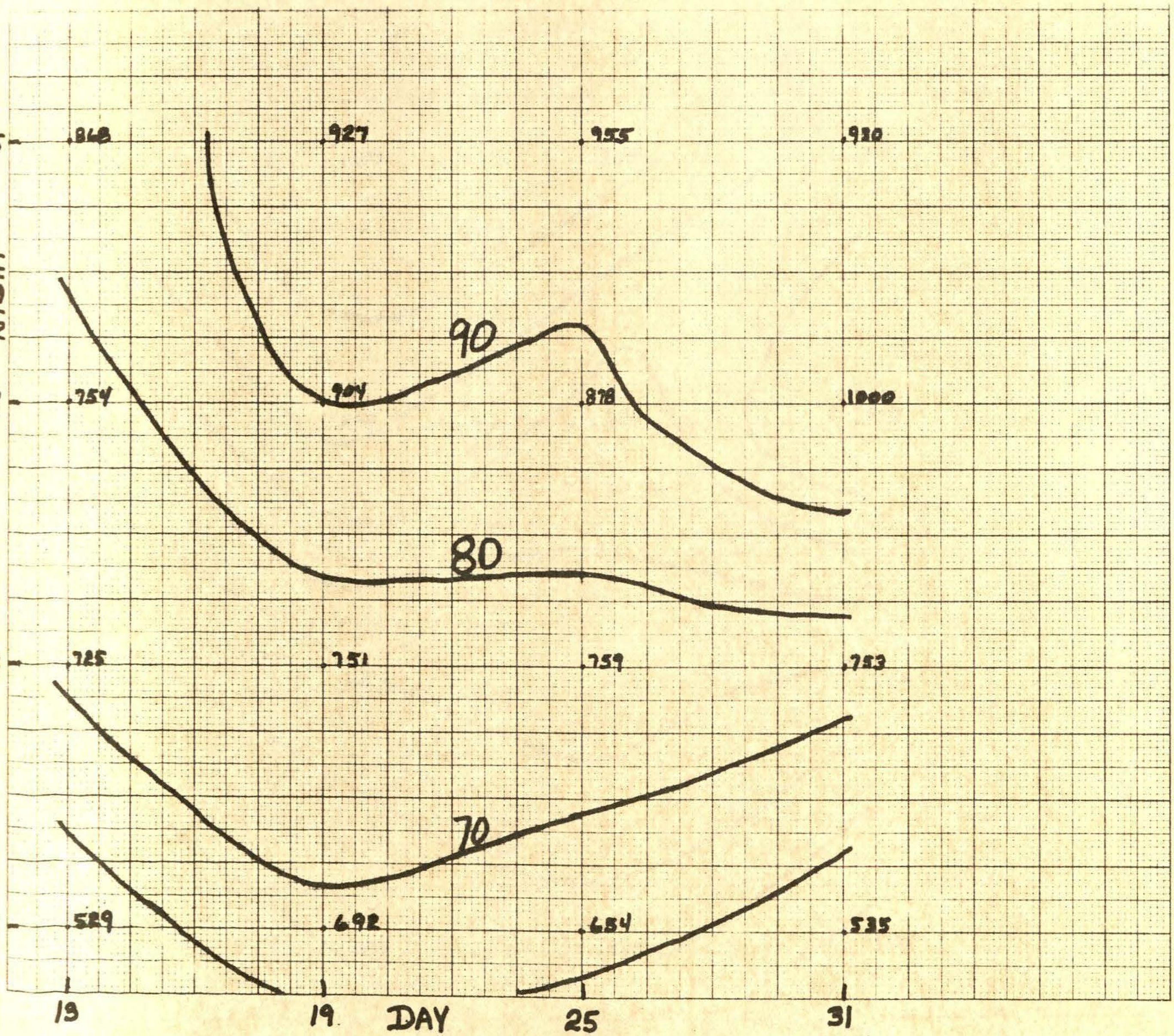


Figure 12.--Growth in percent of maximum as a function of day and night temperature (°C).

Picea glauca Dry Weight (DG-7986 Run I)

Max. Dry Wt. = 0.36 gm

Std. Error = 8.4%

	Day	Night
Optimum (90%)	16 - 26	22 - 26
Acceptable (70%)	13 - 32	18 - 26

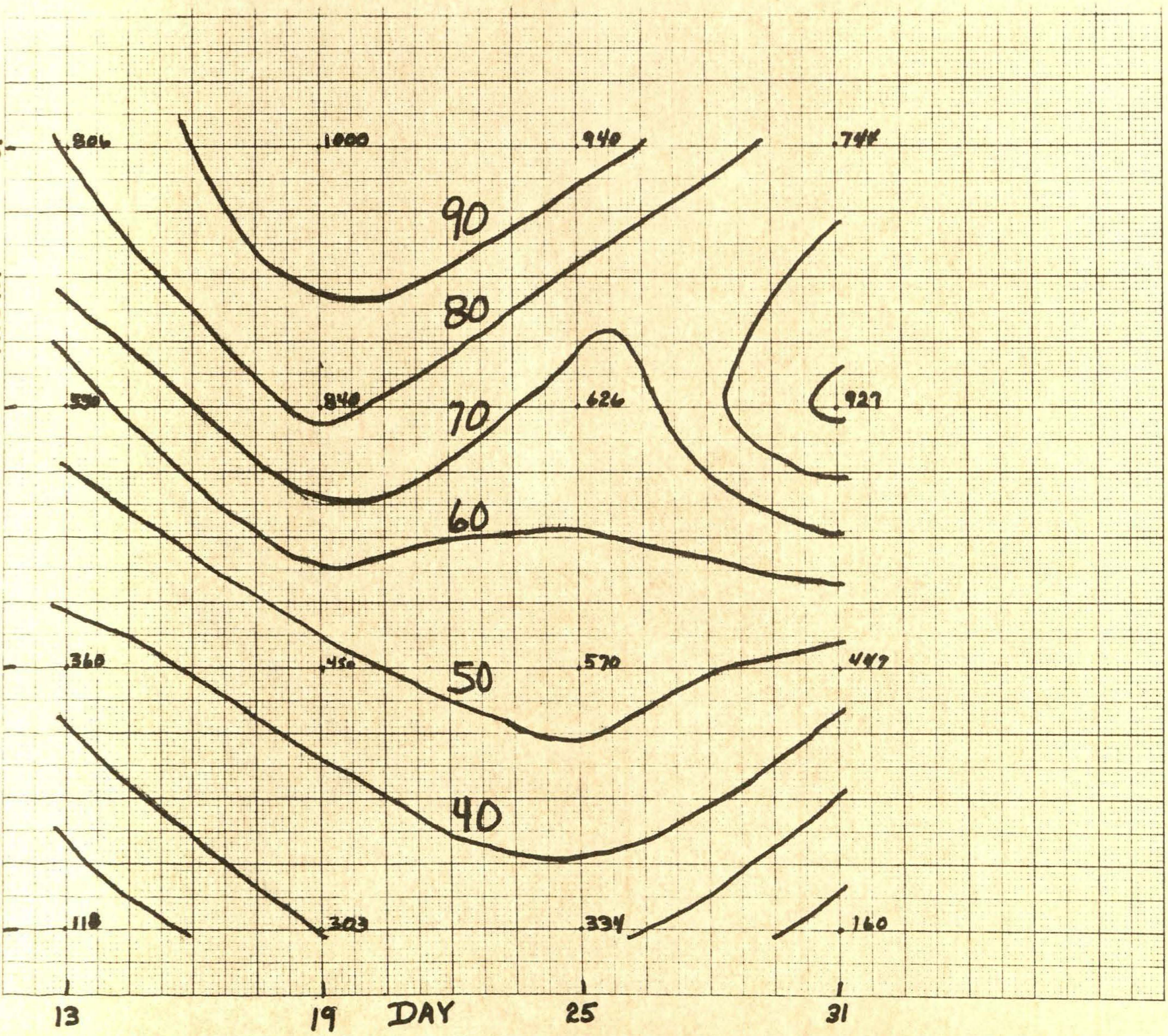


Figure 13.--Growth in percent of maximum as a function of day and night temperature (°C).

Pinus contorta Height (DB-655 Run II)

Max. Ht. = 113 mm

Std. Error = 3.8%

	Day	Night
Optimum (90%)	15-18 or 22-30	21-29 or 12-19
Acceptable (70%)	16-34 Except Cold Night	10-29+ Except Cold Day

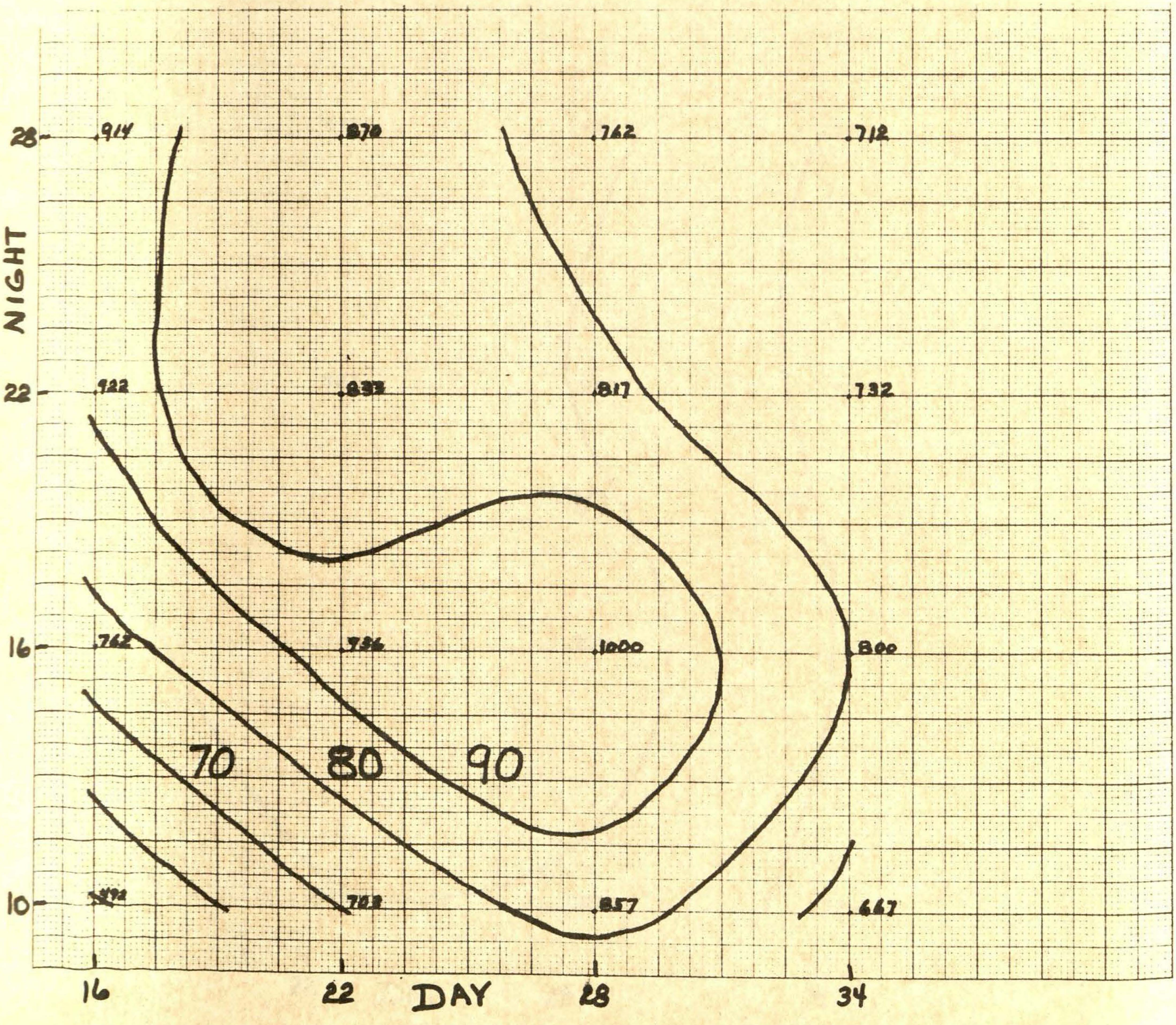


Figure 14.--Growth in percent of maximum as a function of day and night temperature (°C).

Pinus contorta Caliper (DB-655 Run II)

Max. Caliper = 1.82 mm

Std. Error = 3.2%

	Day	Night
Optimum (90%)	16-29 Except Cold Night	10 - 29+
Acceptable (70%)	15- to 35+	9- to 29+

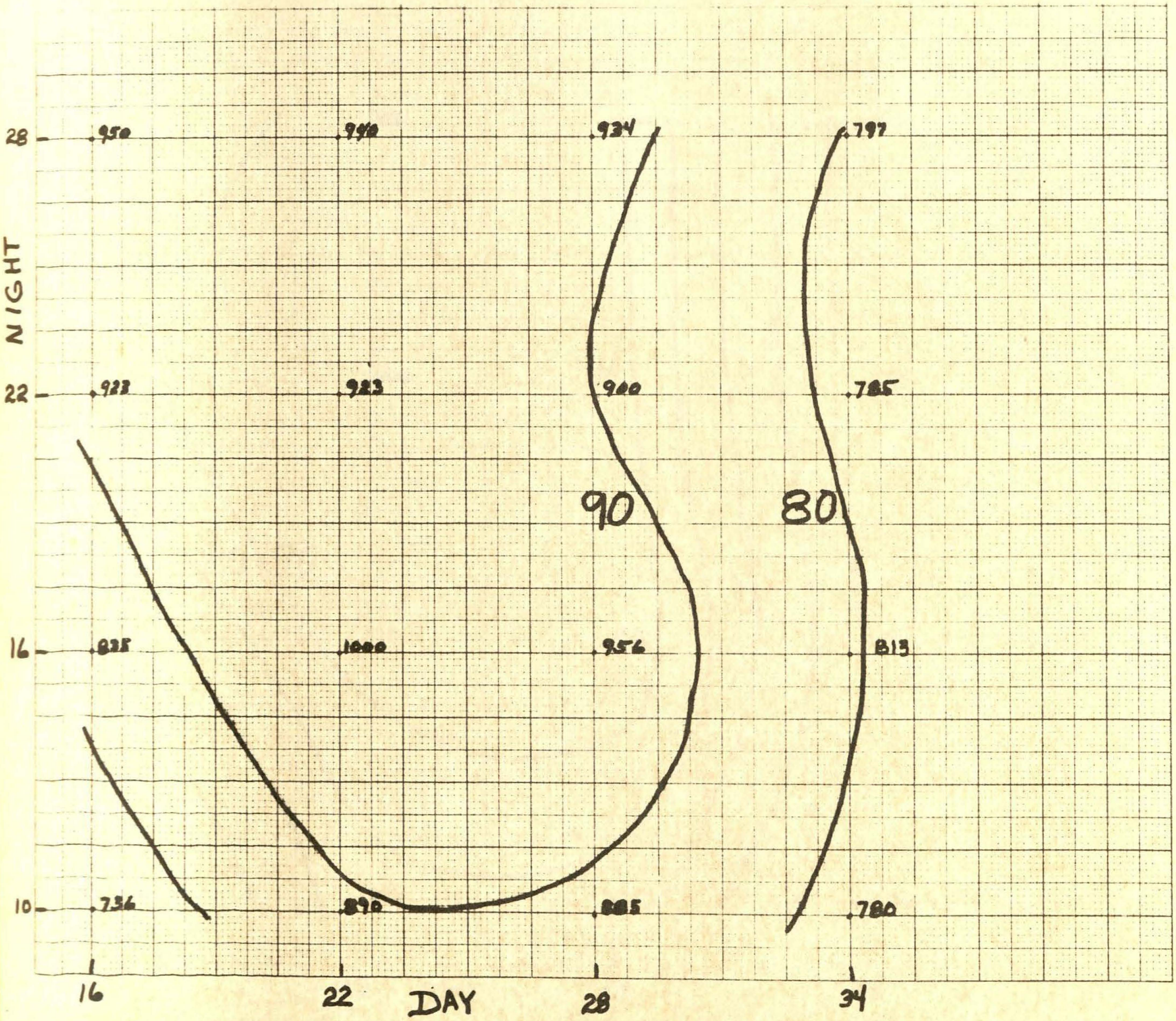


Figure 15.--Growth in percent of maximum as a function of day and night temperature (°C).

Pinus contorta Dry Weight (DB-655 Run II)

Max. Dry Wt. = 0.38 gm

Std. Error = 7.0%

	Day	Night
Optimum (90%)	20 - 28	14 - 29
Acceptable (70%)	16-30 Except Cold Night	10-29+ Except Cold Day

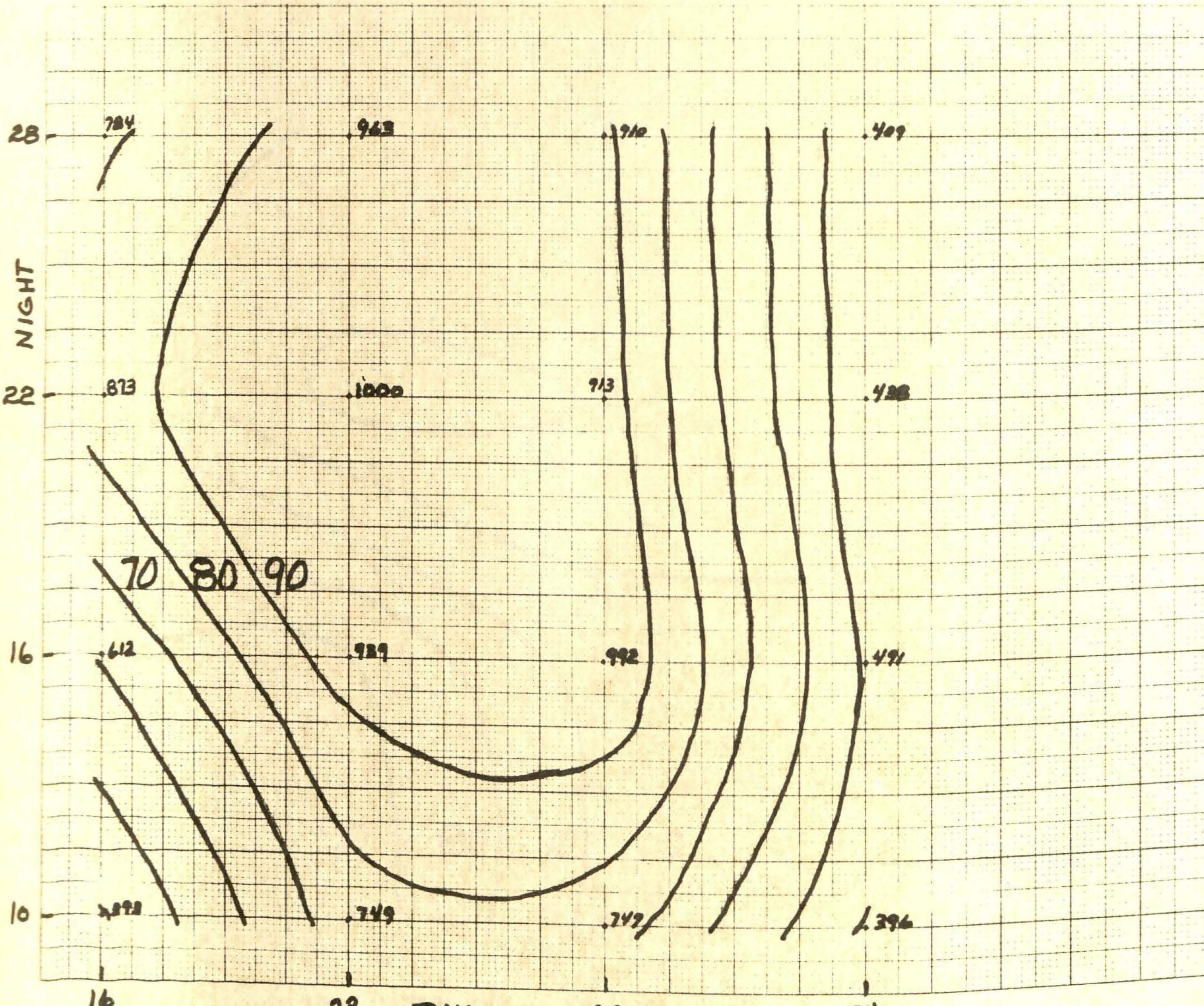


Figure 16.--Growth in percent of maximum as a function of day and night temperature (°C).

Pinus contorta (DB-655 Run II)

Max. Root/Shoot Ratio = .365

	Day	Night
Optimum (90%)	15 - 23	9 - 16
Acceptable (70%)	15 - 27	9 - 19

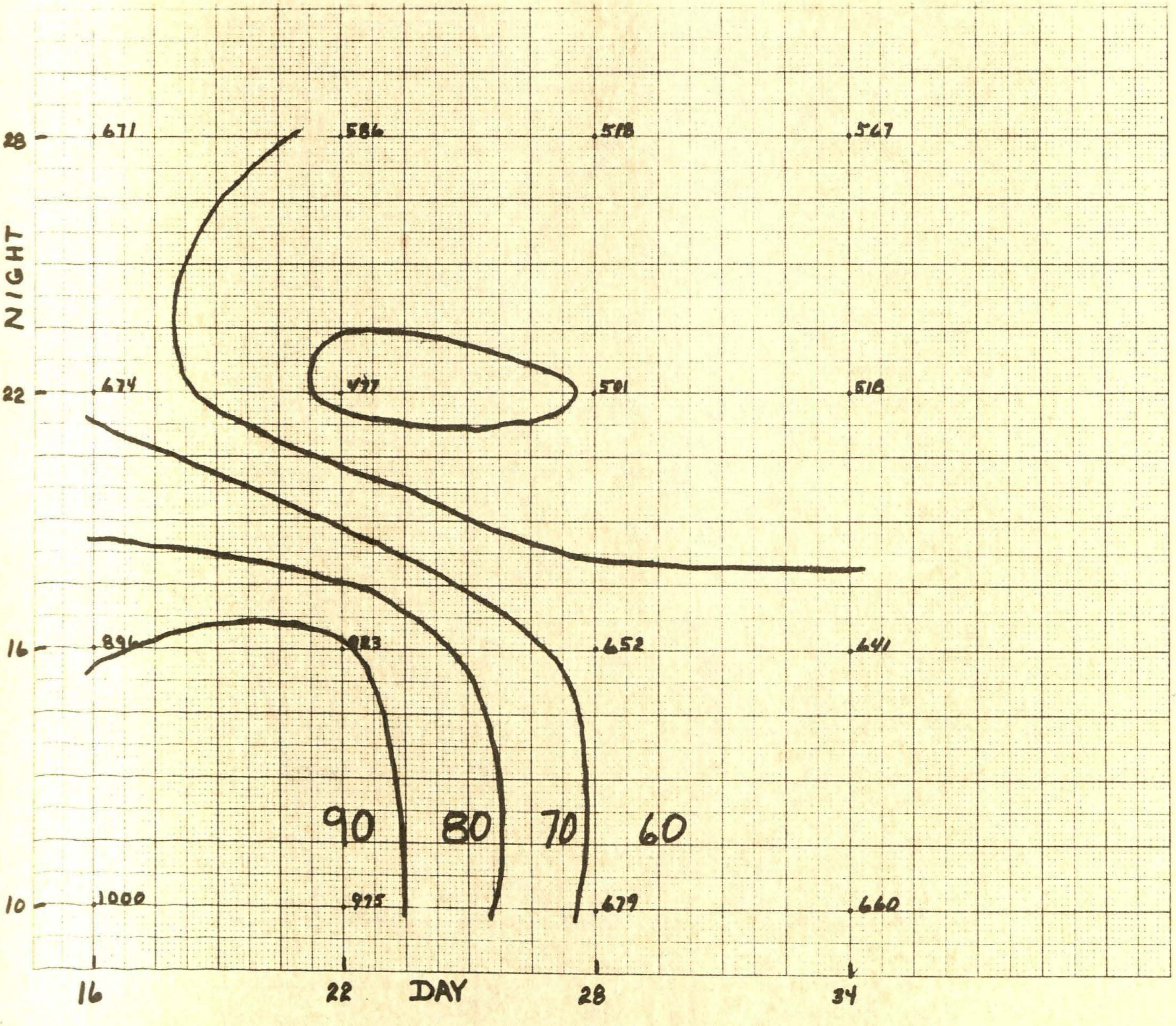


Figure 17.--Growth in percent of maximum as a function of day and night temperature (°C).

Pinus contorta Height (DP-8796 Run II)

Max. Ht. - 124 mm

Std. Error = 3.9%

	Day	Night
Optimum (90%)	25 - 30	11 - 18
Acceptable (70%)	16 - 34	10- to 28+

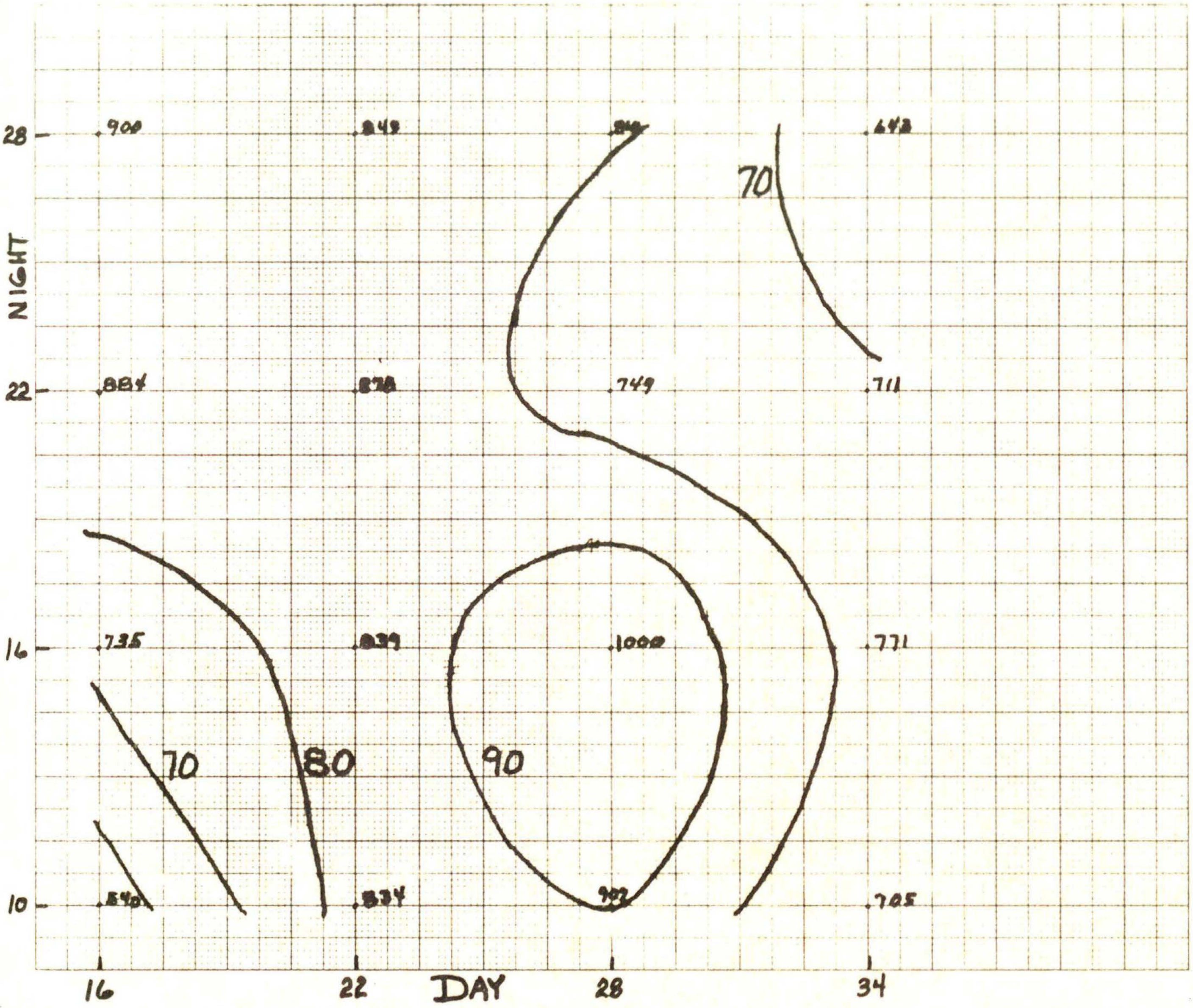


Figure 18.--Growth in percent of maximum as a function of day and night temperature (°C).

Pinus contorta Caliper (DP-8796 Run II)

Max. Caliper = 1.84 mm

St. Error = 2.7%

	Day	Night
Optimum (90%)	16- to 26 or 18-30	17 to 28+ or 10- to 17
Acceptable (70%)	16- to 34+	10- to 28+

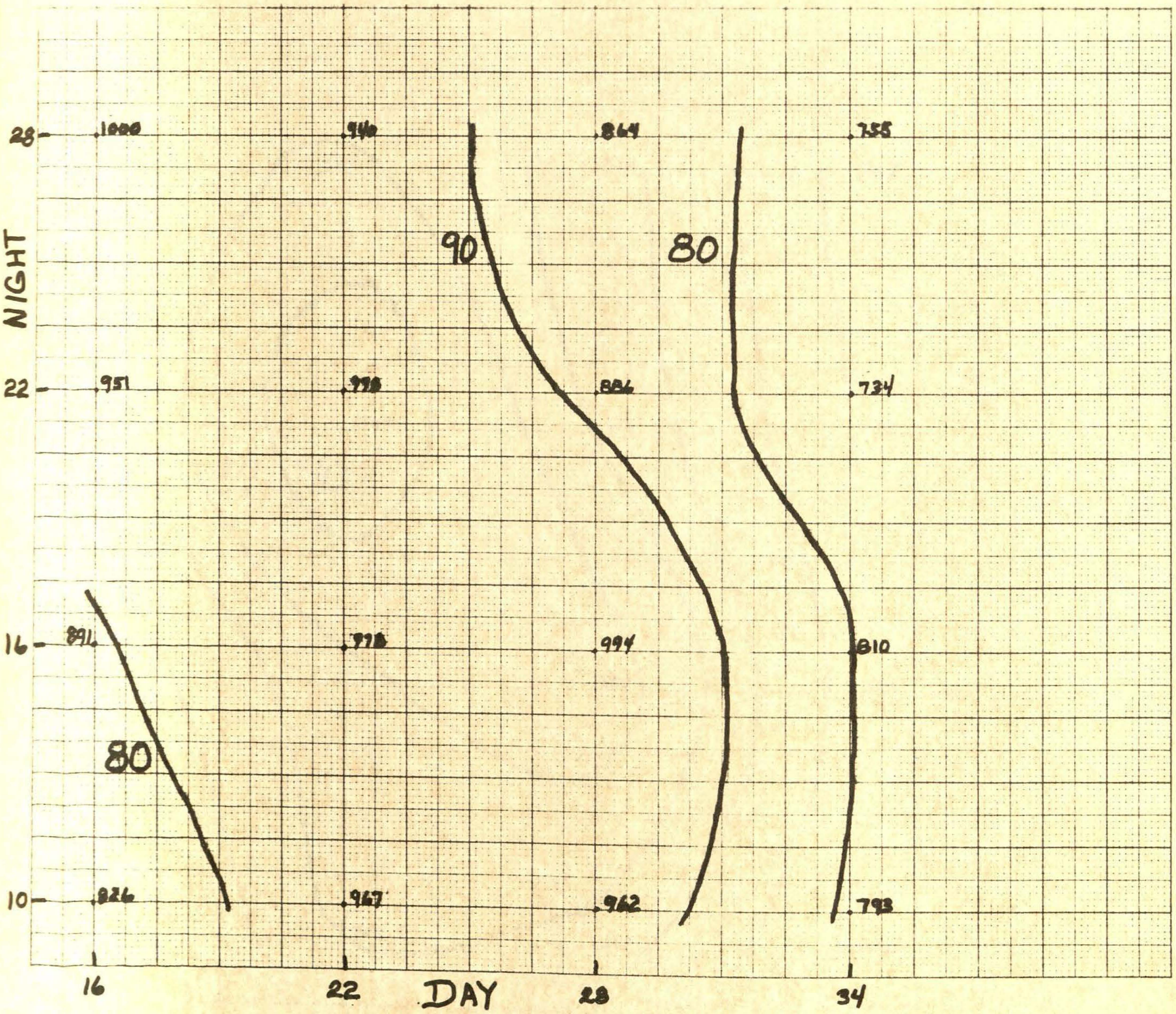


Figure 19.--Growth in percent of maximum as a function of day and night temperature (°C).

Pinus contorta Dry Weight (DP-8796 Run II)

Max. Dry Wt. = 0.56 gm

Std. Error = 6.6%

	Day	Night
Optimum (90%)	20 - 24	20 - 25
Acceptable (70%)	17 - 28	11 - 28+

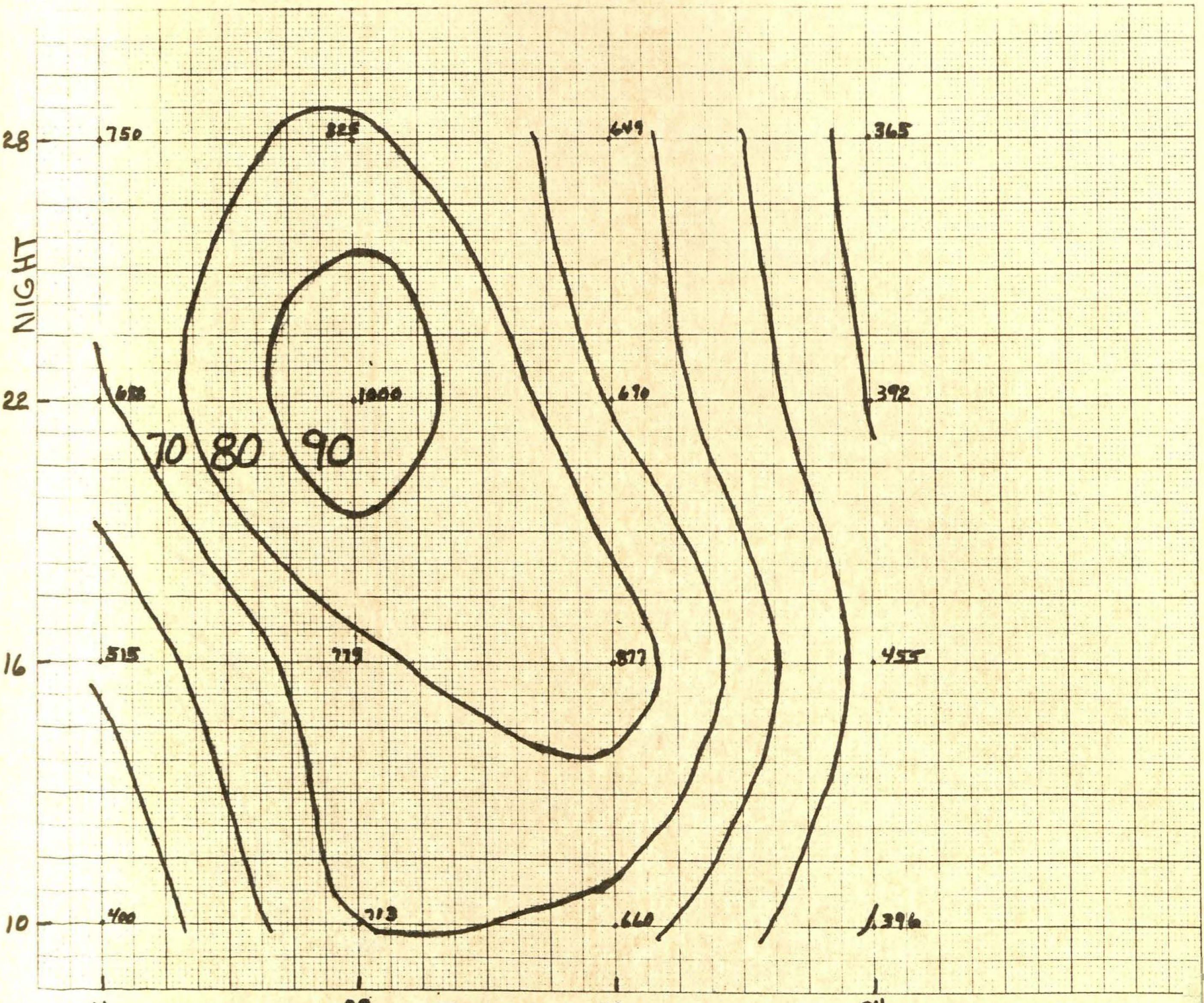


Figure 20.--Growth in percent of maximum as a function of day and night temperature (°C).

Pinus contorta (DP-8796 Run II)

Max. Root/Shoot = .427

	Day	Night
Optimum (90%)	15 - 18	9 - 15
Acceptable (70%)	15 - 22	9 - 18

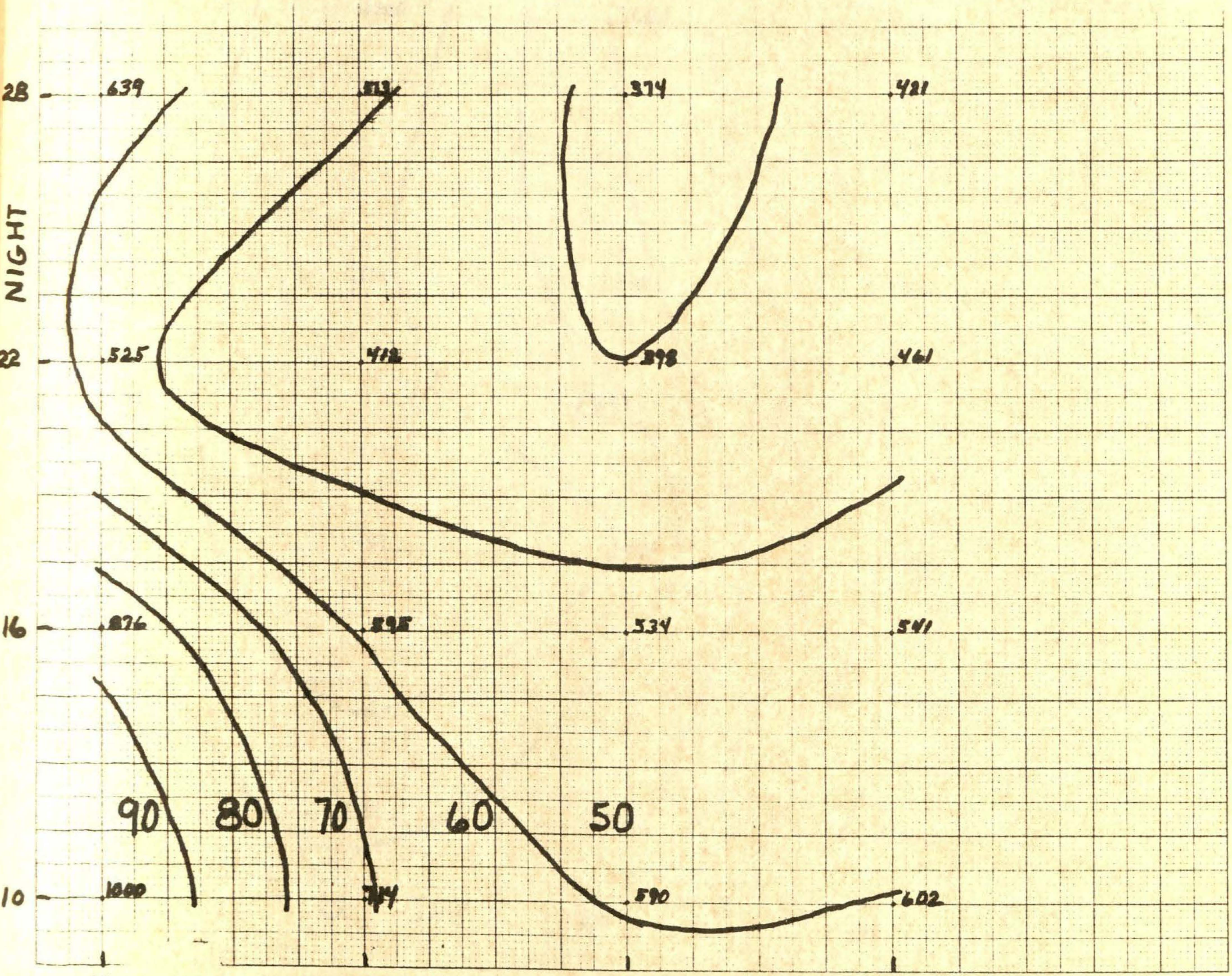


Figure 21.--Growth in percent of maximum as a function of day and night temperature (°C).

Picea glauca Height (DR-46135 Run II)

Max. Ht. = 94 mm

Std. Error = 4.3%

	Day	Night
Optimum (90%)	19 - 25	13 - 29
Acceptable (70%)	15 - 29	9 - 29

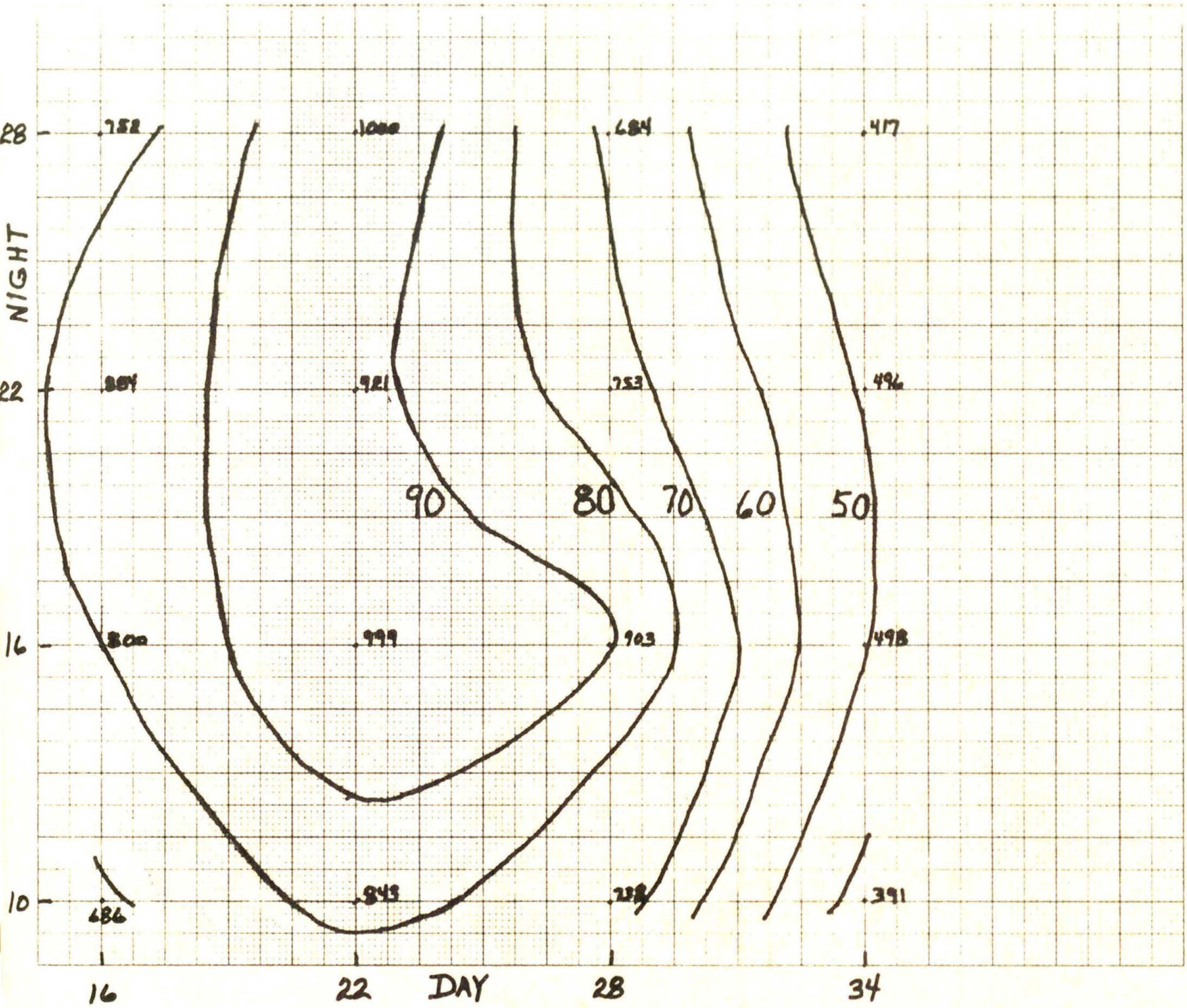


Figure 22.--Growth in percent of maximum as a function of day and night temperature (°C).

Picea glauca Caliper (DR-46135 Run II)

Max. Caliper = 1.57 mm

Std. Error = 4.1%

	Day	Night
Optimum (90%)	19 - 26	10 - 28
Acceptable (70%)	16- to 31	9- to 29+

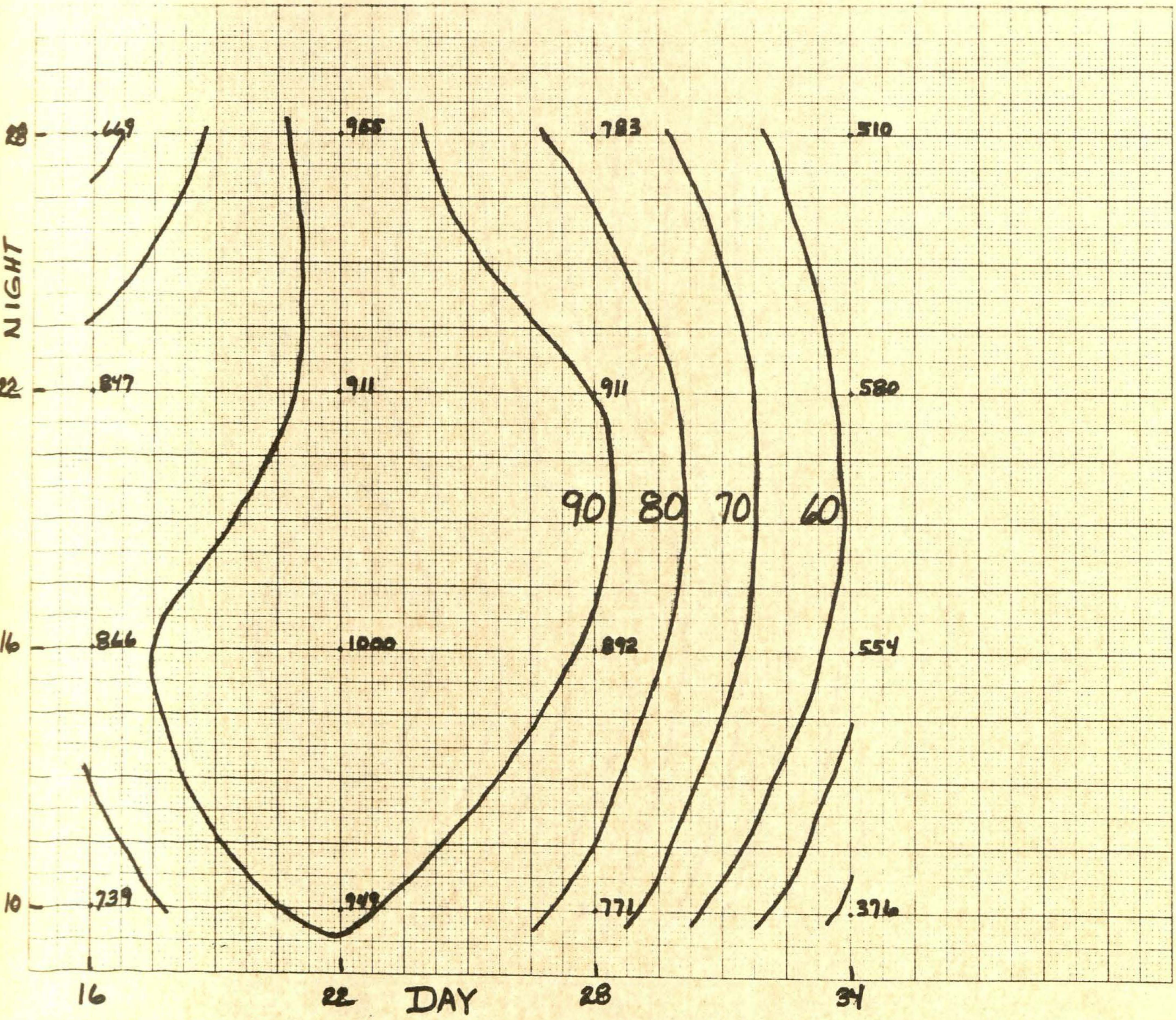


Figure 23.--Growth in percent of maximum as a function of day and night temperature (°C).

Picea glauca Dry Weight (DR-46135 Run II)

Max. Dry Wt. = 0.37 gm

Std. Error = 10.6%

	Day	Night
Optimum (90%)	20 - 24	14 - 20
Acceptable (70%)	17 - 27	10 - 29+

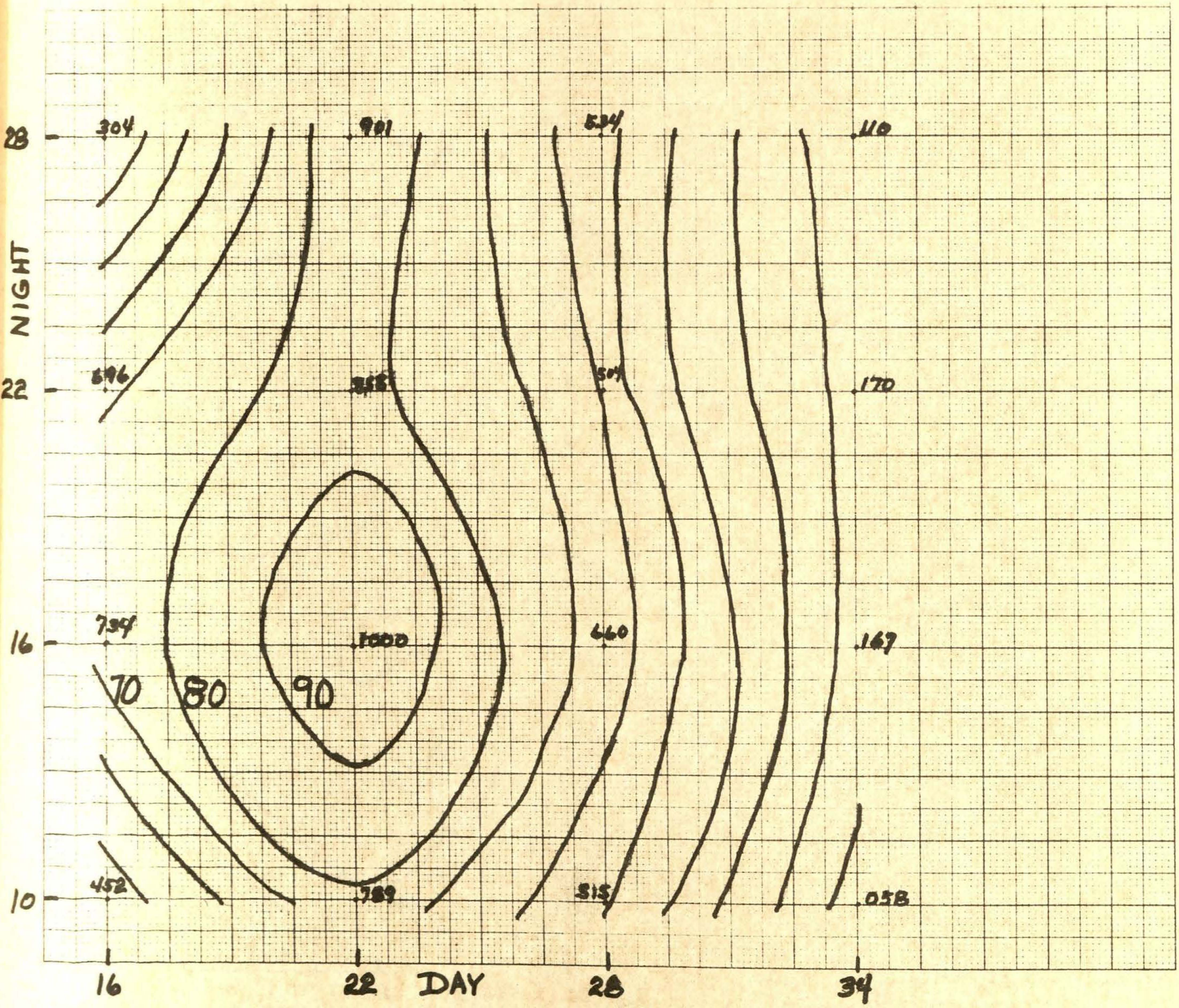


Figure 24.--Growth in percent of maximum as a function of day and night temperature (°C).

Picea glauca (DR-46135 Run II)

Max. Root/Shoot Ratio = .228

	Day	Night
Optimum (90%)	21 - 35	15 - 29
	But Day Temp. ±2 = Night Temp. +6	
Acceptable (70%)	17 - 29	11 - 29

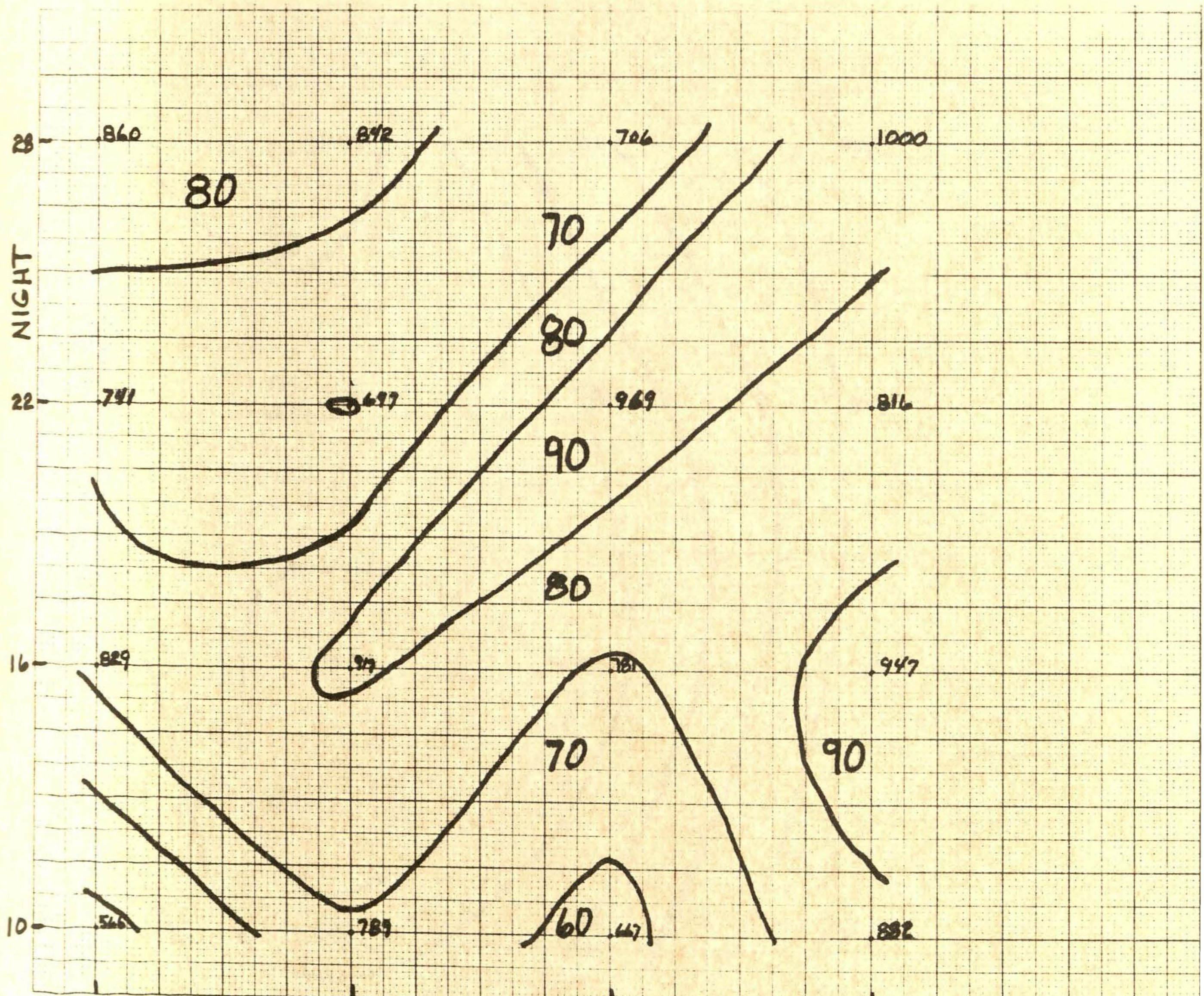


Figure 25.--Growth in percent of maximum as a function of day and night temperature (°C).

Picea glauca Height (DG-7986 Run II)

Max. Ht. = 100 mm

Std. Error = 5.0%

	Day	Night
Optimum (90%)	21-26 or 19-23	12-18 or 26-29
Acceptable (70%)	18 - 29	10 - 29

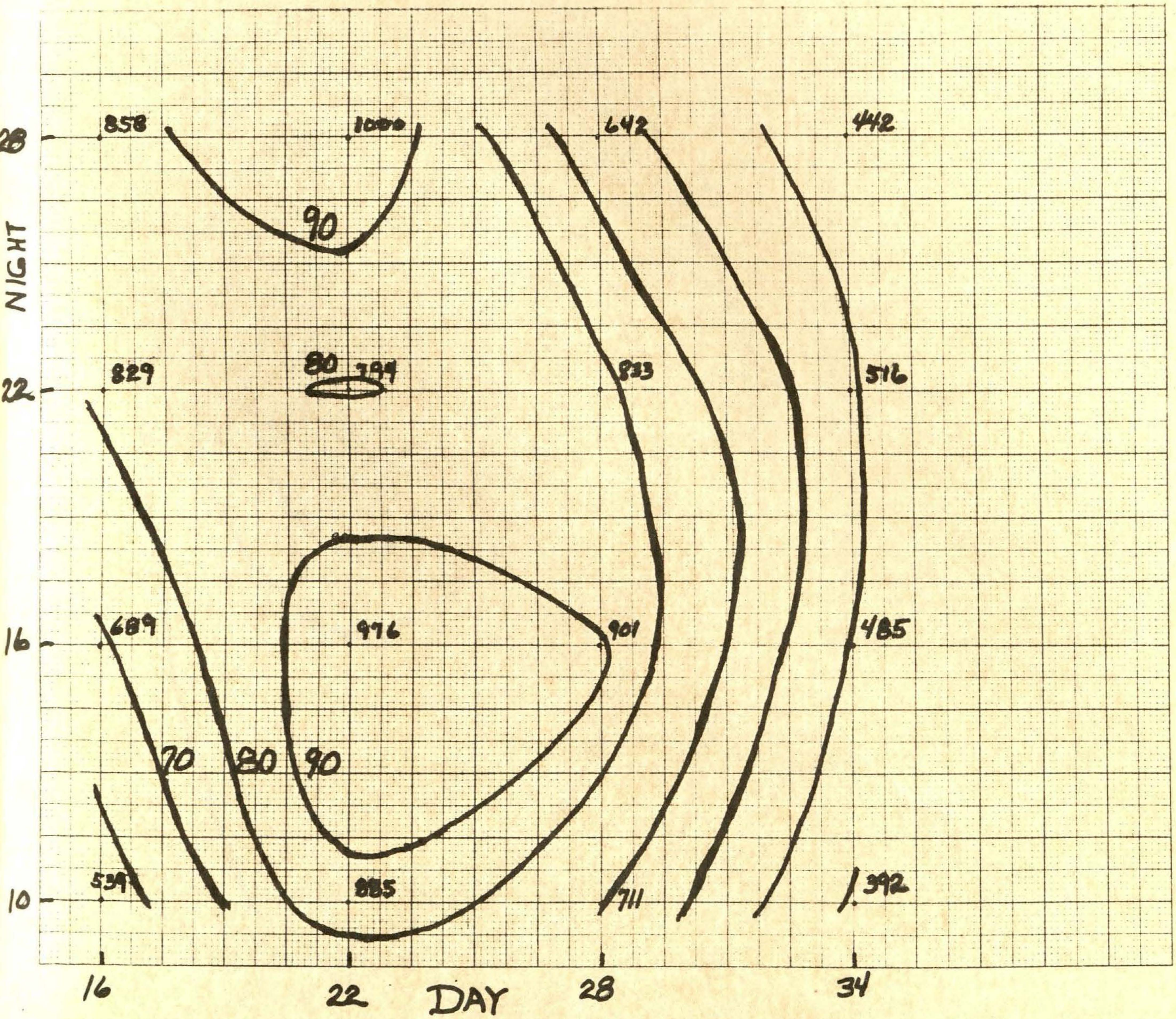


Figure 26.--Growth in percent of maximum as a function of day and night temperature (°C).

Picea glauca Caliper (DG-7986 Run II)

Max. Caliper = 2.24 mm

Std. Error = 4.8%

	Day	Night
Optimum (90%)	21 - 23	20 - 23
Acceptable (70%)	19 - 27	17 - 27

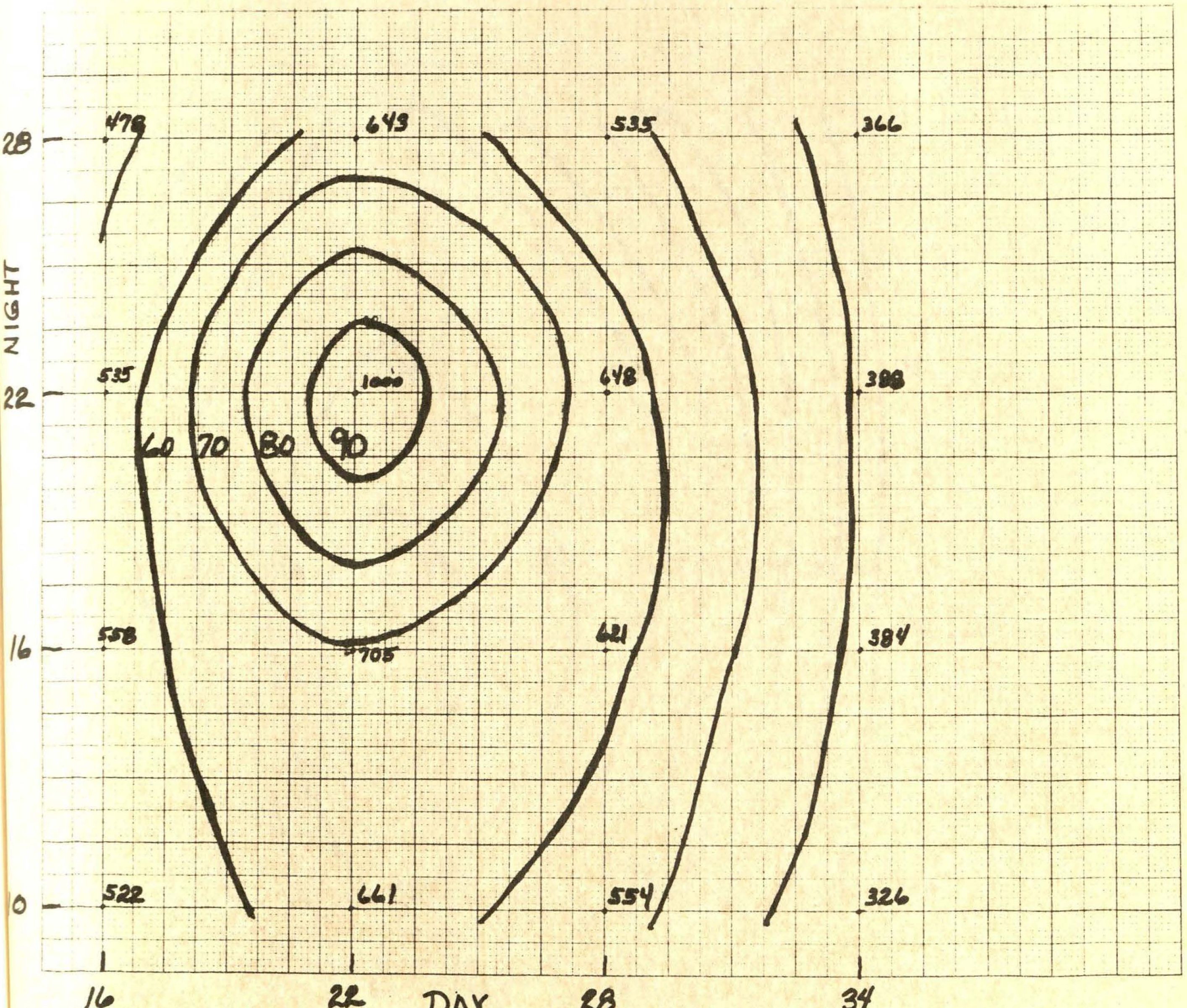


Figure 27.--Growth in percent of maximum as a function of day and night temperature (°C).

Picea glauca Dry Wt. (DG-7986 Run II)

Max. Dry Wt. = 0.36 gm

Std. Error = 11.1%

	Day	Night
Optimum (90%)	21 - 24	13 - 19
Acceptable (70%)	18 - 28	9 - 29

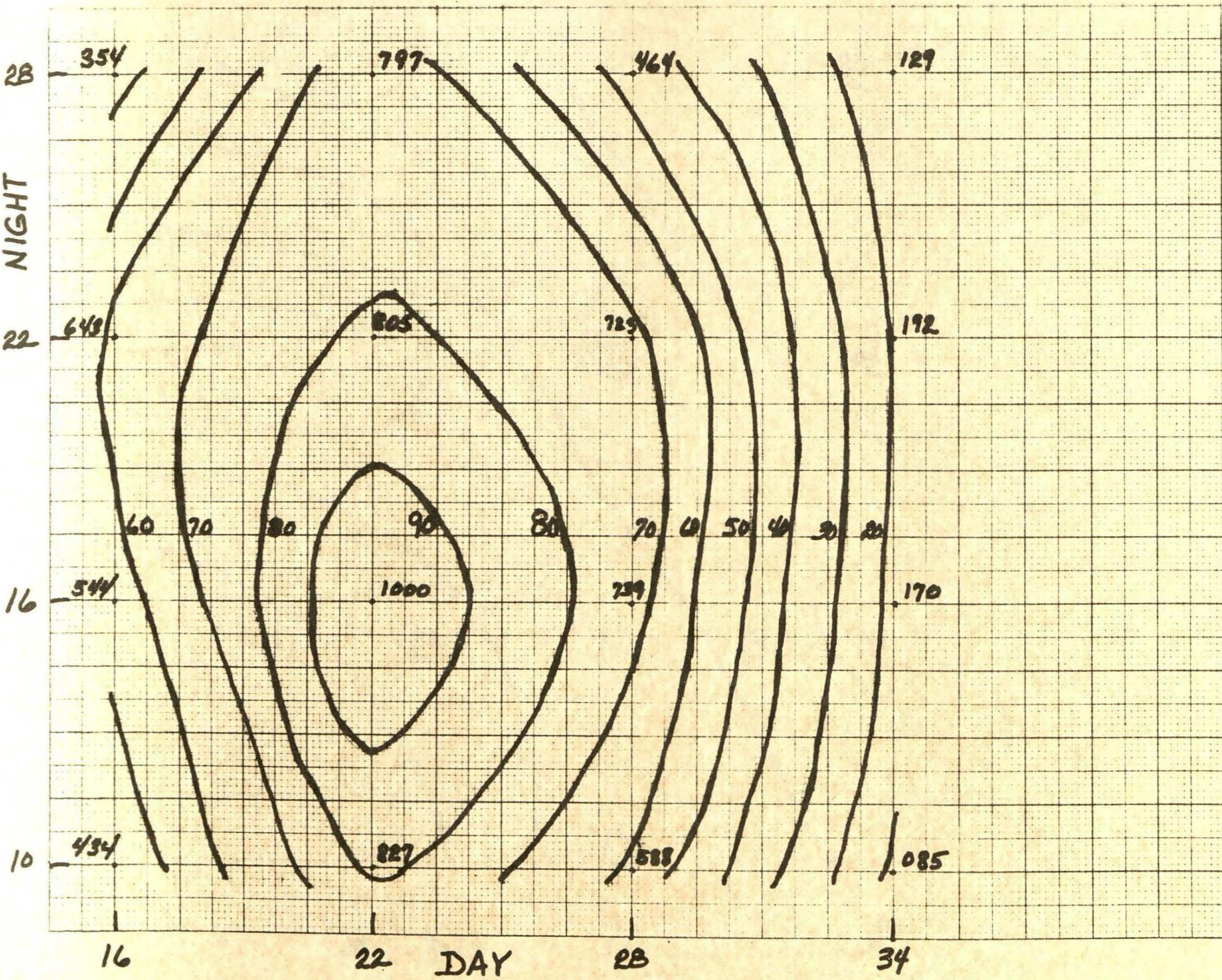
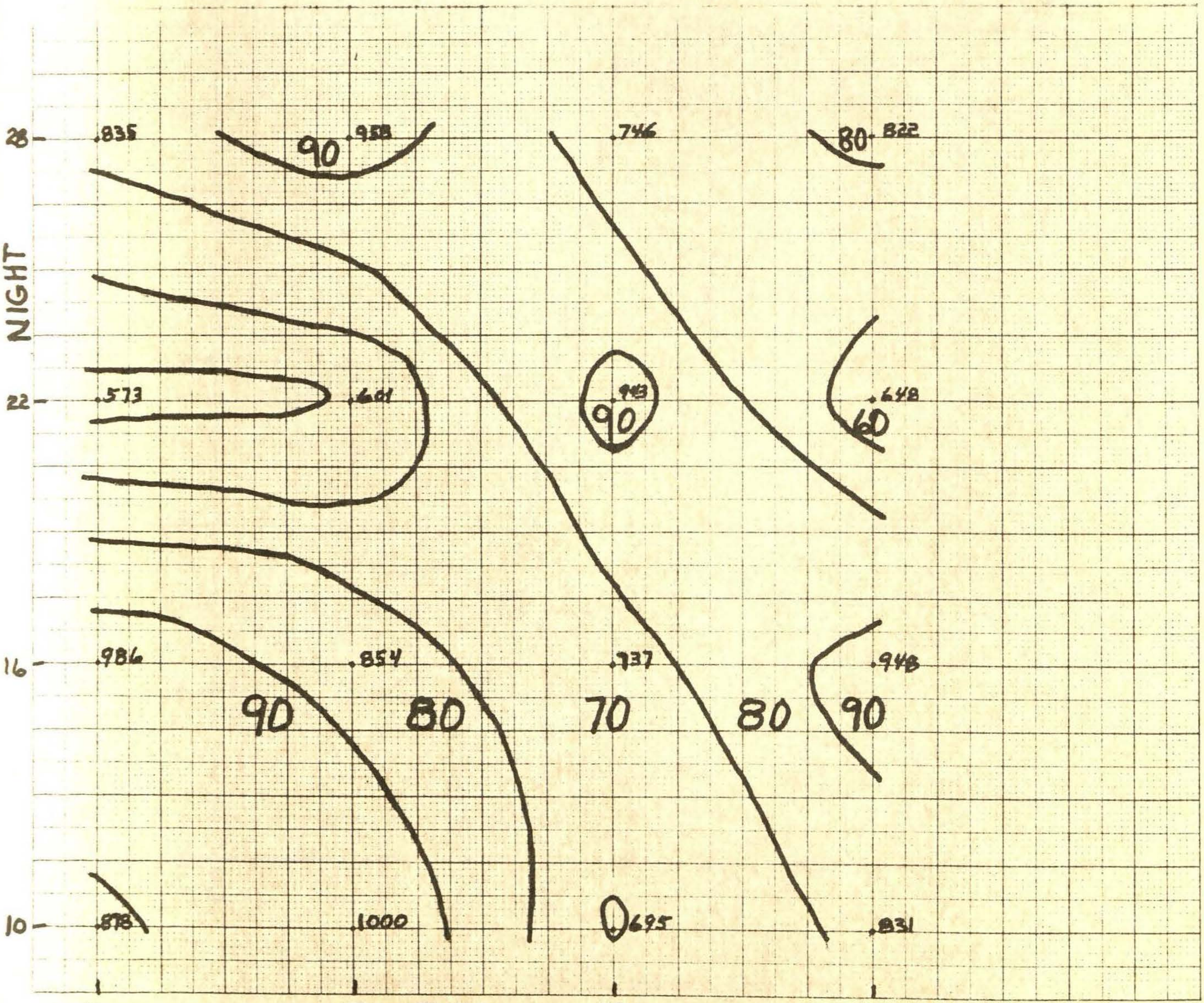


Figure 28.--Growth in percent of maximum as a function of day and night temperature (°C).

Picea glauca (DG-7986 Run II)

Max. Root/Shoot Ratio = .213

	Day	Night
Optimum (90%)	15 - 23	10-17 or 27-28
Acceptable (70%)	16 - 34	10-28 Except at 20-24 low day temp.



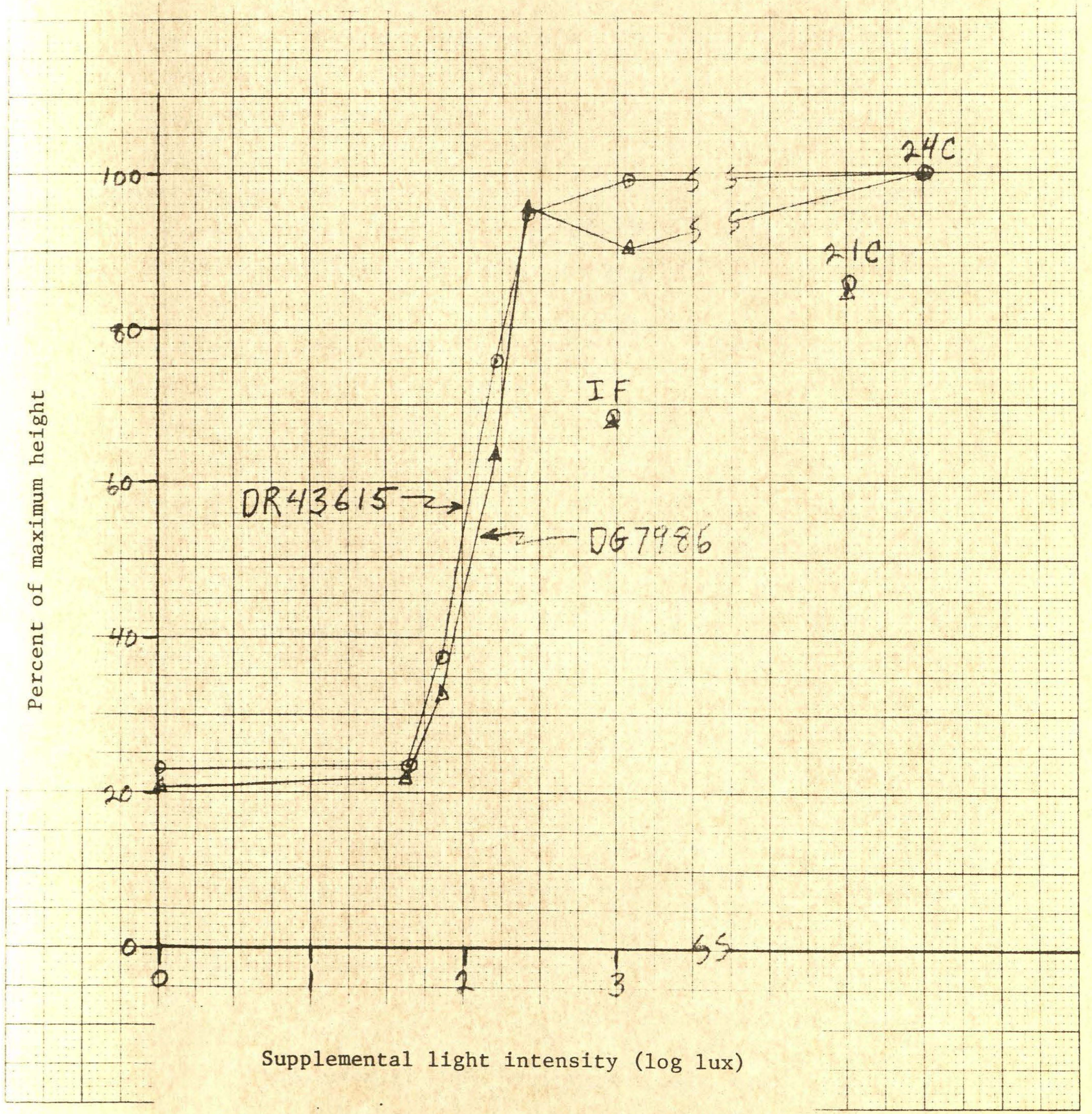
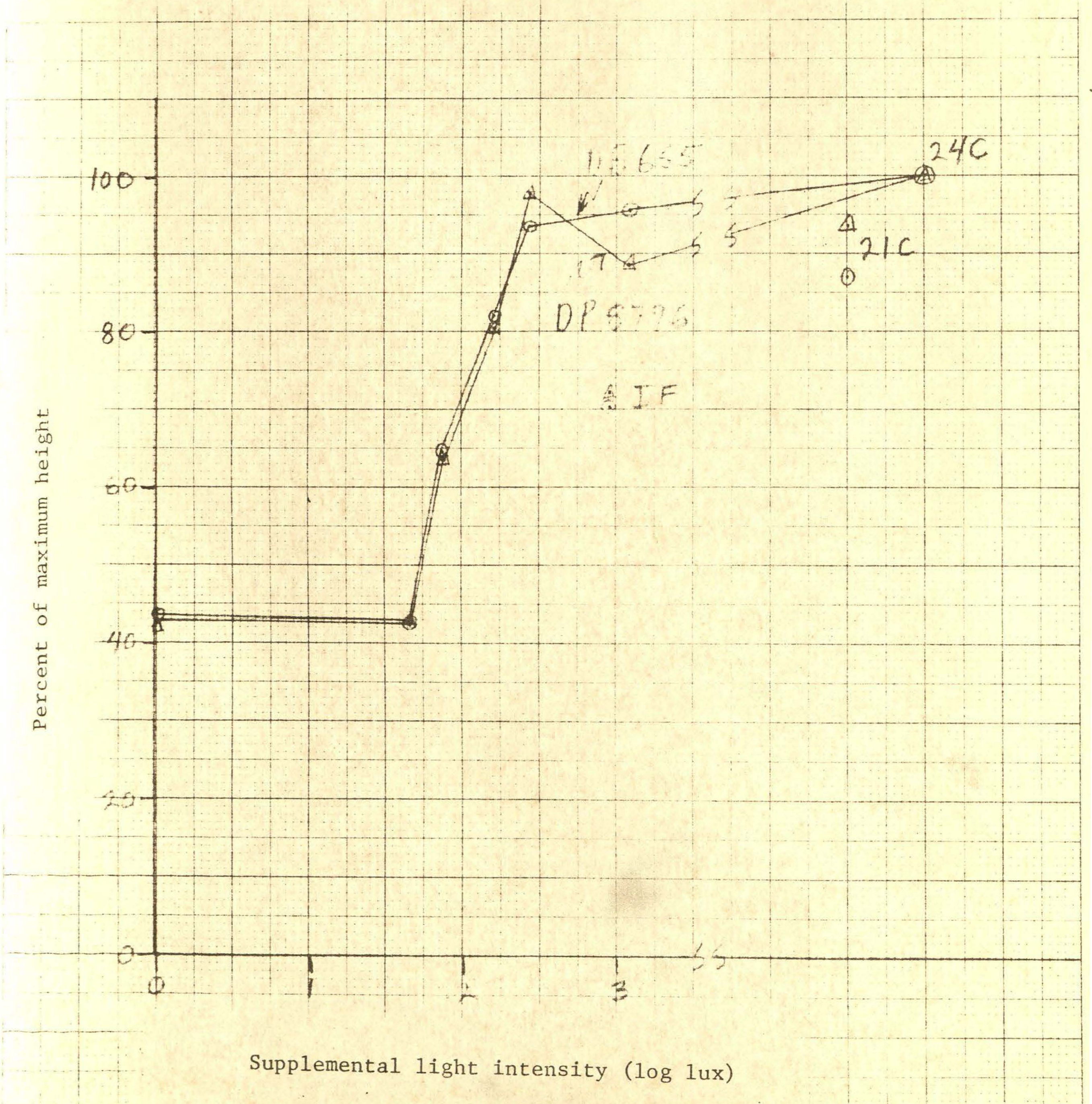


Figure 29.--Height growth response of white spruce to different intensity, duration, and quality of supplemental light. Triangles and circles represent two different seed sources as labelled. Unlabelled points are different intensities of incandescent light given 1 minute out of every 15 during the night. IF indicates intermittent fluorescent light on the same schedule. 21C was continuous incandescent light at 1200 lux with a 3 hr dark period. 24C was the same as 21C with no dark period.

Figure 30.--Height growth response of lodgepole pine to different intensity, duration, and quality of supplemental light. Triangles and circles represent two different seed sources as labelled. Unlabelled points are different intensities of incandescent light given 1 minute out of every 15 during the night. IF indicates intermittent fluorescent light on the same schedule. 21C was continuous incandescent light at 1200 lux with a 3 hr dark period. 24C was the same as 21C with no dark period.



100
80
60
40
20
0
Percent of maximum height
DE 665
24C
17
21C
DP 5776
IF
0
1
2
3
Supplemental light intensity (log lux)